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50th

ANNIVERSARY

1937-1987

50 YEARS OF SERVICE

THIS MONTH:

SE Oregon field trip guide:

Sheaville and Rome zeolite deposits

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER ILLUSTRATION

The Oregon Department of Geology and Mineral Industries is celebrating 1987 as the fiftieth year since its inception. In commemoration of the event, Department cartographer Mark Neuhaus designed and created this special department seal.

OIL AND GAS NEWS

MIST GAS FIELD

Tenneco Oil Company has plugged and abandoned Columbia County 24-28, located in sec. 28, T. 6 N., R. 5 W. Total depth was 1,928 ft.

Oregon Natural Gas Development (ONGD) has commenced drilling at the natural gas storage project at Mist. Located in sec. 10, T. 6 N., R. 5 W., OM 12d-10 was drilled as an observation well to a total depth of 2,805 ft. Two additional observation monitor wells are currently being simultaneously drilled. These are OM 43c-3, located in sec. 3, T. 6 N., R. 5 W., and OM 41a-10, located in sec. 10, T. 6 N., R. 5 W. These wells are permitted to total depths of 3,000 and 3,100 ft, respectively. ONGD will use the depleted Flora and Bruer Pools for gas storage.

DRILLING CONTINUES AT WILLAMETTE VALLEY WILDCAT

Operations continue at Damon Petroleum Corporation's Stauffer Farms 35-1, located in sec. 35, T. 4 S., R. 1 W., Marion County. Because of mechanical difficulties, the operator decided to plug and abandon the 335-ft casing string, skid the rig approximately 30 ft to the north, and commence a new well, where drilling is presently underway.

EPA PREPARES REPORT ON OILFIELD WASTE

The Resource Conservation and Recovery Act requires the Environmental Protection Agency (EPA) to study wastes from oil, gas, and geothermal operations. The final report by EPA is to be finished by August 31, 1987, to be followed by new regulations. An interim Technical Report has been prepared for public review.

The report outlines drilling techniques and describes EPA's proposed method for collecting and analyzing data to address aspects of drilling waste disposal. The public comment period has ended, but questions and perhaps late comments can be registered with Bob Hall of the EPA, phone (202) 475-7415. □

Stinchfield elected DOGAMI Governing Board Chair

At its November 24, 1986, meeting in Portland, the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI) elected Allen P. Stinchfield of North Bend to serve as new Chair of the Board. Stinchfield, who has served on the Governing Board since July 1, 1980, replaces previous Chair Donald A. Haagensen of Portland. □

DOGAMI to celebrate fiftieth birthday

On March 1, 1937, legislation creating the Oregon Department of Geology and Mineral Industries (DOGAMI) was passed. During the fifty years between 1937 and 1987, the State of Oregon has changed, as has the science of geology. We of DOGAMI are grateful to the citizens of Oregon for having allowed us to be a part of both processes.

During this, our fiftieth anniversary year, we will share with you some brief remembrances of the busy and exciting years of the past. But more importantly, we will continue to give you new information about Oregon's geology and related topics. Within its beauty and vastness, Oregon still has many relatively unexplored areas—places where the geology is still not known or understood. We thank you for your interest and support down through the years, and we urge you to join with us in the excitement of learning more about the geology of our wonderful state in the years to come. □

Field trip guide to the Sheaville and Rome zeolite deposits, southeastern Oregon

by R.A. Sheppard, U.S. Geological Survey, Denver Federal Center, and A.J. Gude, 3rd, U.S. Geological Survey, retired, Lakewood, Colorado

Part A of this article is a slightly modified version of "Field Trip Stop 3, Sheaville Zeolite Deposit, Sheaville, Oregon," and Part B is a version of "Field Trip Stops 4 and 5, Rome Zeolite Deposit, Rome, Oregon," both of which originally appeared in *Zeo-Trip '83*, a publication of the International Committee on Natural Zeolites that was used as a guide for the organization's field trip held from July 7 to 10, 1983. The 72-page book, which was edited by F.A. Mumpton, State University College, Brockport, New York, and prepared by R.A. Sheppard, A.J. Gude, 3rd, and F.A. Mumpton, also contains trip logs to the Durkee zeolite deposit (reprinted in the November 1986 issue of *Oregon Geology*); the Castle Creek zeolite deposit in Oreana, Idaho; the Lovelock zeolite deposit in Lovelock, Nevada; and the Tahoe-Truckee water reclamation plant in Truckee, California. In addition, there is a section on the discovery and commercial uses of the zeolite deposits described in the book. Copies of *Zeo-Trip '83* may be purchased prepaid for $12 from the International Committee on Natural Zeolites, c/o Department of Earth Sciences, SUNY, College at Brockport, Brockport, New York 14420. Permission to reprint the Oregon trip stops in *Oregon Geology* is gratefully acknowledged,

—Editor

PART A. SHEAVILLE ZEOLITE DEPOSIT, SHEAVILLE, OREGON (FIELD TRIP STOP 3 IN *ZEO-TRIP '83*)

INTRODUCTION

The Sheaville deposit is located near Sheaville, Malheur County, Oregon, about 72 km southwest of Boise, Idaho. The Sheaville field trip stop (shown as field trip Stop 3 on Figure 1) is to several small prospect pits, about 300 meters (m) east of U.S. Highway 95 and about 4 kilometers (km) north of Sheaville in the N½NE¼ sec. 1, T. 28 S., R. 46 E. (Figures 1 and 2). This southeastern part of Oregon is in the Owyhee Upland physiographic province, a moderately dissected surface about 600-1,800 m above sea level. Upper Cenozoic volcanic and sedimentary rocks underlie most of the region.

Clinoptilolite and associated authigenic minerals at the Sheaville stop occur in a Miocene sequence of fluviatile and lacustrine rocks known as the Sucker Creek Formation of Kittleman and others (1965). Kittleman and others (1967) reported that the Sucker Creek Formation in the Sheaville area unconformably overlies rhyolitic, latitic, and basaltic volcanic rocks of Miocene age and is unconformably overlain by Miocene and Pliocene rhyolitic and basaltic rocks.

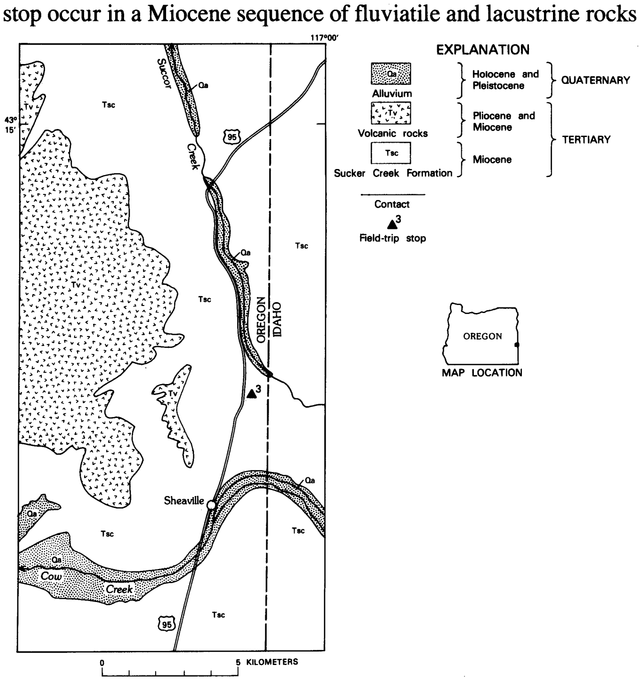

Figure 1. Generalized geologic map showing the field trip stop (Stop 3 in Zeo-Trip '83*) at the Sheaville, Oregon, zeolite deposit discussed in Part A of this paper. Map is modified from Kittleman and others (1967).*

Clinoptilolite in silicic tuffs of the Sheaville area was first recognized by R.H. Olson and F.A. Mumpton in 1958 during an exploration program for zeolites by Union Carbide Corporation. The Norton Company has actively prospected and drilled the zeolite deposits at the field trip stop since the early 1960's, but the company has produced only a small tonnage of zeolitic tuff. Since the late 1970's, clinoptilolite-rich tuff has, however, been mined from the Sucker Creek Formation at other nearby localities. Several thousand tons of clinoptilolite-rich tuff has been mined by Occidental Minerals Corporation about 1 km east of this stop and by Teague Mineral Products about 13 km north of this stop. The materials from both localities have reportedly been used chiefly in agricultural applications. In spite of the commerical interest in the clinoptilolite at the Sheaville deposit, published information on the mineralogy, chemistry, and physical properties of the zeolitic tuff is meager. Kittleman and others (1965) described clinoptilolite and associated authigenic silicate minerals in altered tuffaceous rocks as part of a regional study of the Sucker Creek Formation. More recently, Shedd and others (1982) published a scanning electron micrograph (SEM) of clinoptilolite-rich tuff from the Sheaville deposit.

LITHOLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE SUCKER CREEK FORMATION

The Sucker Creek Formation is about 500 m thick and consists mainly of tuff, volcanic sandstone, arkosic sandstone, conglomerate, and carbonaceous volcanic shale. The formation is extensively exposed in the northeastern part of Malheur County, Oregon (Kittleman and others, 1967) and in the northwestern part of Owyhee County, Idaho (Ekren and others, 1981). In Malheur County, the formation also locally includes flows of basalt and a rhyolitic ash-flow tuff. Much of the vitric material in the sedimentary rocks of the formation is altered to smectite, clinoptilolite, and opal C-T, but fresh glass is preserved locally. Those parts of the formation that are zeolitic or silicified are commonly ledge formers, whereas those parts that are rich in clay minerals or relatively fresh glass are slope formers. In addition to vitric material or altered vitric material, the volcaniclastic rocks commonly contain trace to minor

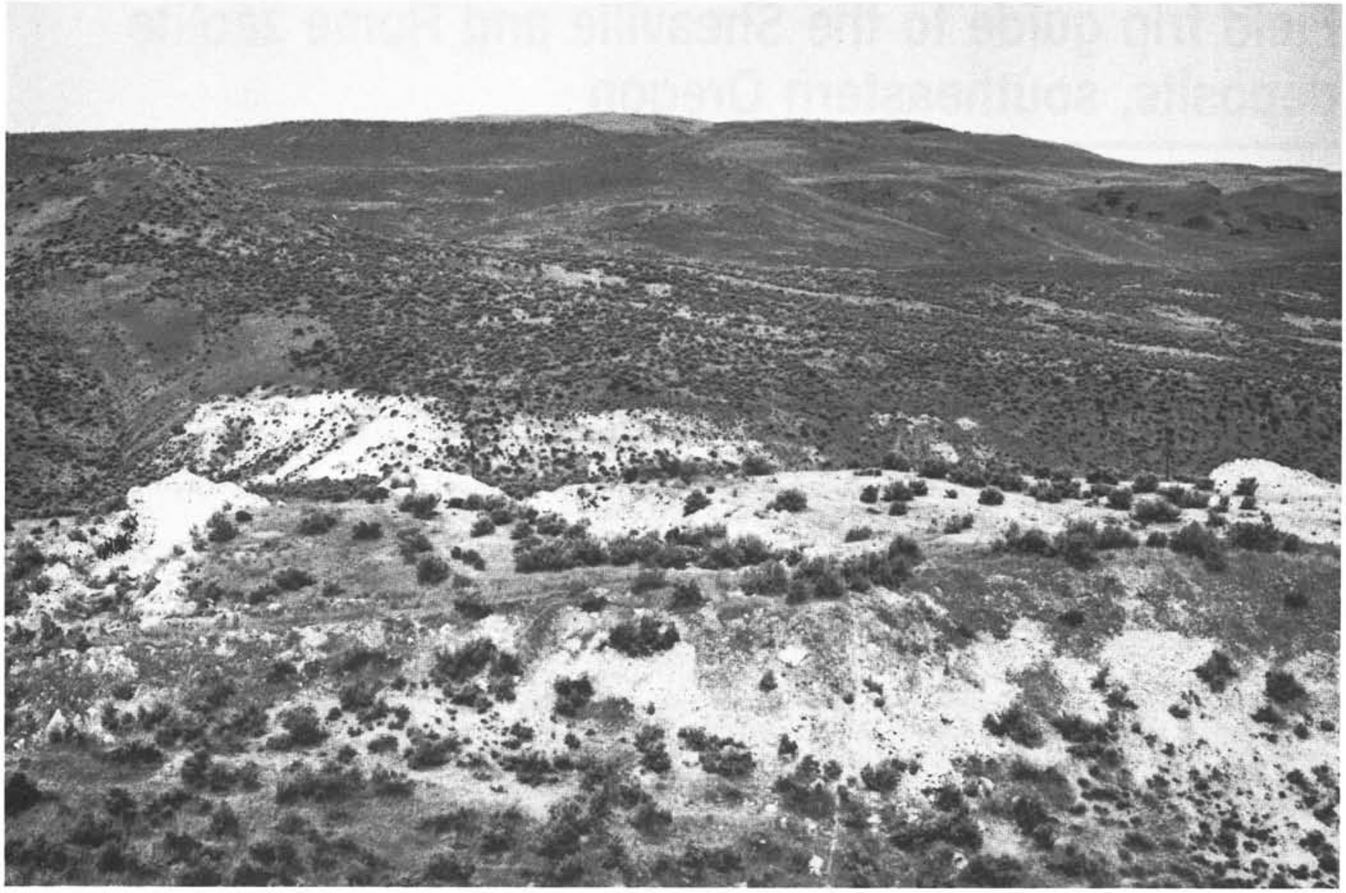

Figure 2. View west to the Sheaville, Oregon, zeolite deposit described in this paper. Bulldozer cuts in the foreground are in light-yellow, clinoptilolite-rich tuff of the Sucker Creek Formation. Hills in the background are underlain by upper Tertiary volcanic rocks that are younger than the Sucker Creek Formation.

amounts of pyrogenic quartz, sodic plagioclase, and biotite. Much of the volcaniclastic material in the formation was probably reworked from ash-fall deposits. Although detailed stratigraphic and sedimentologic studies of the Sucker Creek Formation have not been conducted, Kittleman and others (1965) suggested that the formation is chiefly the result of fluviatile deposition and only subordinate lacustrine deposition.

LITHOLOGY AND MINERALOGY OF THE SHEAVILLE ZEOLITE DEPOSIT AT THIS STOP

Clinoptilolite at the Sheaville zeolite deposit occurs in a thick tuff in the upper part of the Sucker Creek Formation. This locality is on the western limb of a northward-trending anticline, and the tuff dips about 15° northwestward. The tuff is cut by numerous faults of slight displacement. Brown, siliceous, carbonaceous shale underlies the zeolitic tuff and contains abundant well-preserved plant fossils.

The zeolitic tuff is yellowish gray to light gray, thin to thick bedded, moderately resistant, and about 18 m thick (Figure 3). It breaks with a hackly or subconchoidal fracture, and brown iron oxides coat the joint surfaces. Some beds show contorted laminations, and others, more rarely, show ripple marks. Thin lenses of carbonized plant debris are locally common. Although unaltered glass was not recognized in the zeolitic tuff at this locality, the original vitroclastic texture is well preserved. Irregular, green or dark-gray zones in the tuff are hard and siliceous.

X-ray diffraction (XRD) patterns of bulk samples of the tuff at this stop indicate that clinoptilolite generally makes up 70 percent or more of the tuff. The other authigenic constituents are opal C-T and smectite. A chemical analysis of the clinoptilolite-rich tuff is given in Table 1 and indicates that the clinoptilolite is a potassic variety. SEM's of the clinoptilolite-rich tuff (Figure 4) show the excellent preservation of the morphology of the original glass shards by the finely crystalline clinoptilolite. Figure 5 shows that the clinoptilolite occurs as plates and blades, commonly 2-10 micrometers (μm) long. This SEM is not representative of the entire sample, however, because most fields of view show the clinoptilolite as an aggregate of anhedral particles.

Figure 3. Clinoptilolite-rich tuff exposed in a bulldozer cut at the Sheaville, Oregon, zeolite deposit at the stop described in Part A of this paper. Bedding dips northwestward (to the left). The moderately resistant tuff breaks with a hackly to subconchoidal fracture.

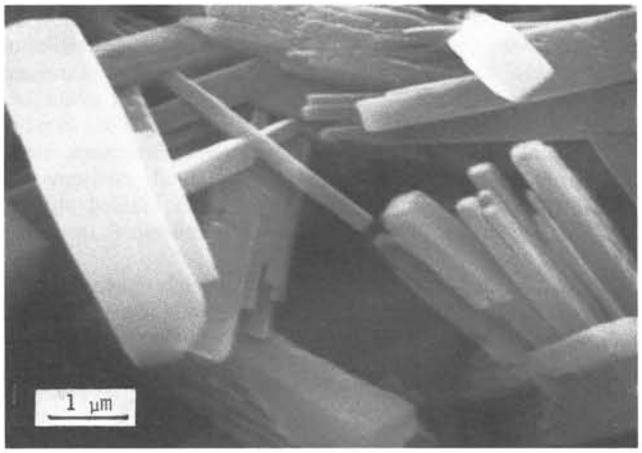

Figure 4. Scanning electron micrograph (SEM) showing the vitroclastic texture in clinoptilolite-rich tuff from the Sheaville, Oregon, zeolite deposit.

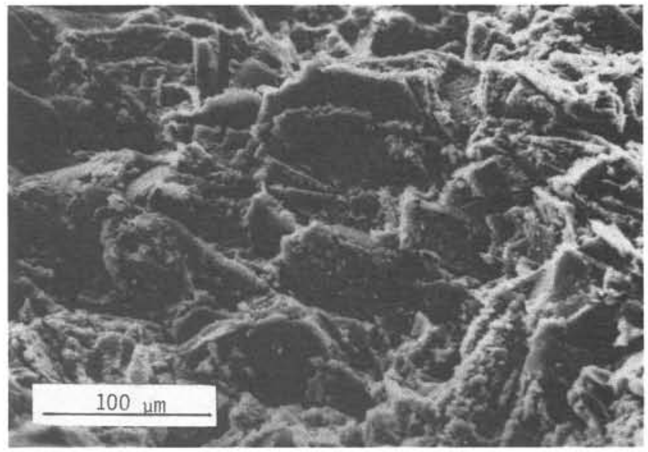

Figure 5. SEM showing plates and finely crystalline clinoptilolite from the Sheaville, Oregon, zeolite deposit.

ZEOLITE GENESIS

No published studies exist concerning the genesis of clinoptilolite and associated authigenic silicate minerals in the tuffs at the Sheaville zeolite deposit or anywhere in the Sucker Creek Formation. The zeolitic tuff originally consisted of silicic volcanic glass (Table 1) that was deposited in a fresh-water environment. Clinoptilolite, smectite, and opal C-T undoubtedly formed during diagenesis by reaction of the silicic glass with interstitial water. The apparent fresh-water depositional environment would probably not have provided connate interstitial water having characteristics favorable for alteration of the glass. Thus, the interstitial water necessary for the diagenetic alteration probably was flowing or percolating ground water that originated as meteoric water. In such open hydrologic systems, the ground water becomes chemically modified by hydrolysis and solution of the vitric material, and zeolitization can then proceed (Hay and Sheppard, 1977).

Additional data are needed with regard to the alteration pattern in the Sucker Creek Formation. Directly at this stop, the vitric material of the tuff seems completely altered. About 1 km north of the stop in the highway cuts and topographically lower than the stop, the same tuff is chiefly unaltered, gray glass. Also, about 1 km east of the stop and at about the same elevation, a tuff stratigraphically lower than that at this stop is completely altered to clinoptilolite, smectite, and opal C-T. At the type section for the Sucker Creek Formation, which is about 32 km north of this stop, Kittleman and others (1965) described both fresh and altered parts of the formation. A regional investigation, including subsurface information, is necessary before the zeolitization of tuffaceous rocks in the Sucker Creek Formation is understood.

Table 1. *Chemical analyses of vitric tuff and clinoptilolite-rich tuff from the Sucker Creek Formation, near Sheaville, Oregon.*[1]

Vitric tuff[2]				Clinoptilolite-rich tuff[3]			
SiO_2	69.1	K_2O	4.76	SiO_2	65.1	K_2O	4.76
Al_2O_3	11.7	TiO_2	0.31	Al_2O_3	11.4	TiO_2	0.34
Fe_2O_3	2.32	P_2O_5	<0.05	Fe_2O_3	2.64	P_2O_5	<0.05
MgO	0.27	MnO	0.04	MgO	0.28	MnO	<0.02
CaO	1.00	H_2O[4]	8.60	CaO	1.01	H_2O[4]	11.70
Na_2O	1.30	Total	99.40	Na_2O	1.71	Total	98.94

[1] X-ray spectrographic analyses on untreated samples by J. S. Wahlberg, Bartel, J. Baker, K. Stewart, and J. Taggert.
[2] Vitric tuff collected in roadcut of U.S. Highway 95, about 0.8 km north of field trip Stop 3. Sample consists of about 80% vitric material and 20% clinoptilolite, opal C-T and smectite.
[3] Clinoptilolite-rich tuff collected at field trip Stop 3. Except for a trace of smectite, the sample consists of clinoptilolite.
[4] H_2O determined by loss on ignition at 900°C.

PART B. ROME ZEOLITE DEPOSIT, ROME, OREGON (FIELD TRIP STOPS 4 AND 5 IN *ZEO-TRIP '83*)

INTRODUCTION

The Rome zeolite deposit is located near Rome, Malheur County, Oregon, about 140 km southwest of Boise, Idaho. This southeastern part of Oregon is also in the Owyhee Upland physiographic province. Neogene and Quaternary volcanic and sedimentary rocks are the principal rocks that crop out in the province. The zeolites and associated authigenic minerals occur in a Miocene sequence of alluvial and lacustrine volcaniclastic rocks known informally as the Rome beds (Figure 6). Walker and Repenning (1966) mapped the Rome beds during their geologic reconnaissance of the Jordan Valley quadrangle. The nearly flat-lying Rome beds unconformably overlie other Miocene sedimentary and volcanic rocks and are locally uncomformably overlain by basalt and sedimentary rocks of Pliocene and Quaternary age.

Although the Rome beds were briefly described by I.C. Russell as early as 1903, zeolites were not recognized until the late 1950's. During this period and in the 1960's, several companies, including Kennedy Minerals Company (Eberly, 1964), Norton Company (Regis and Sand, 1966; Sand and Regis, 1967), Shell Development Company (Studer, 1967), and Union Carbide Corporation, conducted exploration programs for zeolites in the Rome beds. Both Anaconda Minerals Company (Santini and LeBaron, 1982) and Occidental Minerals Company actively prospected and drilled the Rome deposit in the late 1970's, and at least two other companies prospected the zeolitic beds for fluorite in the 1970's. In spite of all the interest and activity concerning the Rome zeolite deposit since the 1950's, only a minor tonnage of zeolite, chiefly mordenite-rich ore, has been produced. A considerable amount of low-grade, erionite-rich tuff containing substantial unaltered ash was quarried from the area for dimension stone prior to 1960.

Published studies on the distribution and genesis of zeolites and associated authigenic minerals in the volcaniclastic rocks of the Rome beds include those of Sheppard and Gude (1969, 1974), Wolf and Ellison (1971), Campion (1979), and Santini and LeBaron (1982). These studies concentrated mainly on that part of the Rome beds between the Owyhee River and Crooked Creek and chiefly north of U.S. Highway 95 (Figure 6). Both field trip stops at the Rome zeolite deposit are in the same general area and are shown as field trip stops 4 and 5 in Figure 6.

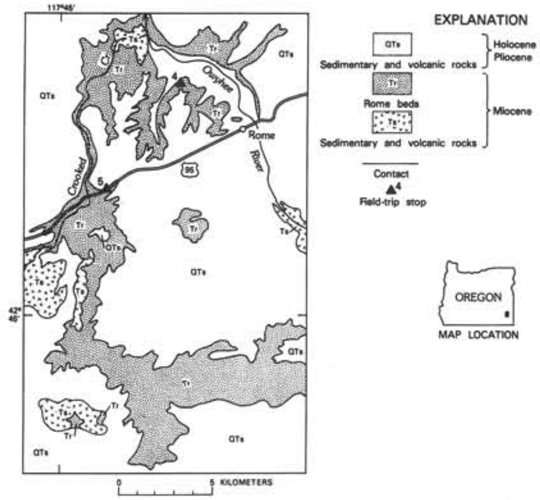

Figure 6. Generalized geologic map of the Rome, Oregon, area, modified from the reconnaissance map of Walker and Repenning (1966), showing the field trip stops (Stops 4 and 5 in Zeo-Trip '83) *at the Rome zeolite deposit discussed in Part B of this paper.*

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS IN THE ROME BEDS

Details of the stratigraphy and depositional environments of the Miocene Rome beds have been reported by Wolf and Ellison (1971) and by Campion (1979), so only a summary will be given here. The Rome beds are at least 100 m thick and consist of an alluvial and lacustrine sequence of chiefly conglomerate, sandstone, mudstone, tuff, and minor limestone and chert. The rocks of the Rome beds are volcaniclastic except for minor chert, limestone, and, possibly, mudstone. Campion (1979) divided the Rome beds into two informal units: (1) a lower, coarse-grained unit that consists of interbedded conglomerate, sandstone, siltstone, and minor mudstone and tuff, and (2) an upper, fine-grained unit that consists chiefly of mudstone, tuff, and minor sandstone and chert. The lower part of the fine-grained unit intertongues with the upper part of the coarse-grained unit. The lower, coarse-grained unit makes up about two-thirds of the thickness of the Rome beds and can be traced over an area, elongated north-south, of about 550 km². The upper, fine-grained unit, however, is traceable over an area of only about 20 km² and is restricted to a narrow north-south band in the west-central part of the basin. The upper, fine-grained unit may originally have had a greater extent, but the marginal parts of the unit were eroded prior to the deposition of the Pliocene and younger rocks overlying it.

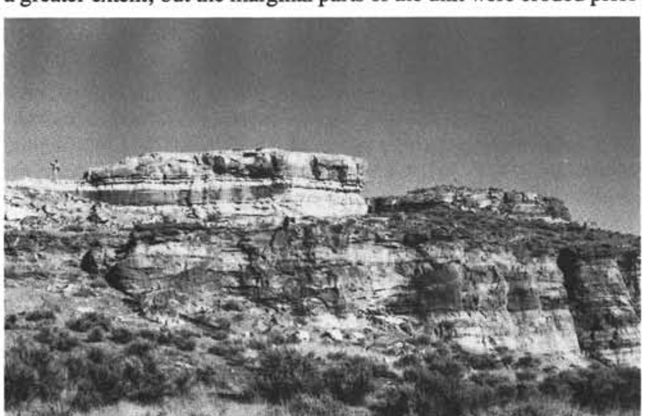

Figure 7. Erionite-rich lower marker tuff (right of 1.8-m-tall standing person) and underlying rocks of lower, coarse-grained member of the Rome beds, at the first trip stop described in Part B, which discusses the deposits at Rome, Oregon.

The lower, coarse-grained unit of the Rome beds consists of channel-form, tabular and sheetlike deposits of pebble conglomerate, coarse-grained sandstone, sandy mudstone, and minor mudstone. According to Campion (1979), these rocks were deposited in proximal braided stream and alluvial fan environments. Basinward, coeval deposits of the lower, coarse-grained unit are chiefly sandstone and mudstone that represent deposition in distal braided stream, floodplain, mudflat, beach, and offshore ephemeral lacustrine environments.

The upper, fine-grained unit of the Rome beds represents a late phase of deposition in the basin. It consists chiefly of mudstone and tuff but includes minor sandstone, chert, and limestone that are laterally extensive, unlike the rocks of the underlying coarse-grained unit. The upper, fine-grained unit of the Rome beds was probably deposited in a perennial lake.

LITHOLOGY AND MINERALOGY OF THE LOWER AND UPPER MARKER TUFFS AND ASSOCIATED ROCKS IN THE ROME BEDS

The two field trip stops at the Rome deposit (shown as stops 4 and 5 in Figure 6) are at thick, conspicuous zeolitic tuffs that herein are termed the lower marker tuff and the upper marker tuff. The lower marker tuff is in the upper part of the lower, coarse-grained unit of the Rome beds and is well exposed in the Rome Cliffs southwest of the Owyhee River, about 5 km northwest of the hamlet of Rome. The upper marker tuff is in the upper part of the upper, fine-grained member of the Rome beds and crops out along Crooked Creek and several tributaries that join Crooked Creek from the east (see Figure 6). The upper marker tuff is in the same unit as the marker tuff of Sheppard and Gude (1969), the upper marker tuff of Campion (1979), and the zeolitic tuff of Santini and LeBaron (1982).

FIRST STOP AT THE ROME BEDS (STOP 4 IN *ZEO-TRIP '83*): LOWER MARKER TUFF

The lower marker tuff and underlying rocks are easily examined at this stop (Stop 4), which is located on the west side of a small gulch in the NW¼ NW¼ sec 22, T. 31 S., R. 41 E. About 40 m of the lower, coarse-grained member of the Rome beds is well exposed at this locality (Figure 7). The lower marker tuff caps small knobs on the ridge west of the gulch, and the underlying grayish-green to grayish-brown sequence consists mainly of sandstone and conglomerate, with minor mudstone, siltstone, and tuff. The conglomerate is lenticular and consists chiefly of pebbles and cobbles of dark-colored chert and volcanic rocks. Pebbles of zeolitic tuff are also locally present in the conglomerate. The mineralogy of the lower marker tuff and underlying rocks is given in Table 2. In addition to detrital constituents, the volcaniclastic sandstone contains authigenic clay minerals, clinoptilolite, and most commonly, erionite.

At this locality, the lower marker tuff is about 6 m thick, but elsewhere it is only about 3 m thick. The lower marker tuff is light yellowish green but weathers brown to orange. The tuff is chiefly massive but is locally platy in the upper part (Figure 8). The base of the tuff is uneven, and cross-bedded tuffaceous sandstone or conglomerate locally occupies the basal part of the tuff. Saline-mineral molds occur locally in the upper part of the tuff. Although unaltered glass shards have not been recognized in this particular tuff unit at this locality, the relict vitroclastic texture is obvious. On the hilltop about 0.4 km east of this locality, the lower marker tuff has been quarried for local building stone and contains some unaltered glass.

The mineralogy of bulk samples of the lower marker tuff collected at this site is given in Table 2. Erionite is the principal authigenic constituent, but minor (10-20 percent) clay minerals, phillipsite, and chabazite occur locally with the erionite. SEM's of the lower marker tuff show that the erionite occurs as needles, rods, and clusters of acicular crystals that are generally 5-20 μm in length

Figure 8. Erionite-rich lower marker tuff at the first field trip stop (Stop 4 in Figure 6) at Rome, Oregon, showing the upper platy part of the unit.

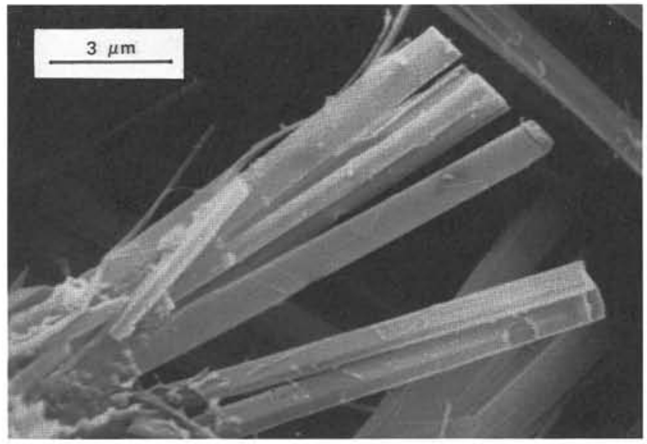

Figure 10. SEM of the lower marker tuff, Rome, Oregon, showing hexagonal rods of erionite.

(Figures 9 and 10). The erionite rods commonly display a hexagonal cross-section. Chabazite occurs as rhombohedra, generally 3-10 µm in size. Thin fibers or needles of erionite have commonly grown on the surfaces of the chabazite (Figure 11), attesting to the younger age of the erionite. The paragenetic relationships as determined by scanning electron microscopy are, from early to late, smectite, chabazite, and then erionite. Neither the morphology nor the paragenetic relationship of the associated phillipsite was determined in the lower marker tuff.

Table 2. *Mineralogical composition of the lower marker tuff and associated rocks at the first stop (Stop 4 in* Zeo-Trip '83*) at the Rome, Oregon, zeolite deposit.*

Lithology	Position[2] (m)	X-ray diffraction analysis[1] (in parts of ten)								
		Ch	Cp	Er	Ph	K-spar	Pl	Qtz	Mica	Sm
Tuff	+6.05	1	-	3	1	-	2	3	tr	tr
Tuff	+4.57	-	-	10	-	-	-	-	-	-
Tuff	+3.50	2	-	6	-	-	1	1	-	-
Tuff	+0.97	-	-	10	tr	-	-	-	-	-
Sandstone, tuffaceous	+0.45	-	-	2	-	-	3	4	-	1
Tuff, gray	-0.10	-	tr	-	-	6	-	1	1	2
Sandstone	-2.74	-	tr	1	-	-	1	5	2	1
Tuff pebble	-18.60	-	-	10	-	-	-	-	-	tr
Sandstone, tuffaceous	-20.34	-	-	2	-	-	1	3	2	2
Siltstone, tuffaceous	-23.85	-	-	2	-	-	1	2	3	2

[1]Ch = chabazite; Cp = clinoptilolite; Er = erionite; Ph = phillipsite; K-spar = potassium feldspar; Qtz = quartz; Mica = illite, muscovite, biotite; Sm = 14-Å clay mineral; tr = trace; - = looked for but not detected.
[2]Stratigraphic position of sample above (+) or below (-) base of lower marker tuff.

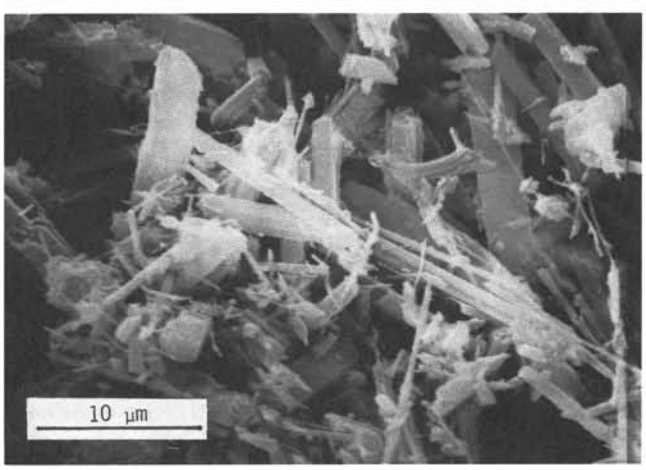

Figure 9. SEM of the lower marker tuff, Rome, Oregon, showing acicular erionite of various sizes.

A thin (0-20 centimeter [cm]) gray tuff is locally present beneath the lower marker tuff at this stop. This gray tuff consists mainly of authigenic potassium feldspar with minor to trace amounts of authigenic clay minerals and clinoptilolite. The presence and, especially, the abundance of authigenic potassium feldspar are unusual for volcaniclastic rocks of the lower, coarse-grained member of the Rome beds.

SECOND STOP AT THE ROME BEDS (STOP 5 IN *ZEO-TRIP '83*): UPPER MARKER TUFF

The upper marker tuff and underlying rocks of the upper, fine-grained member of the Rome beds crop out just north of U.S. Highway 95, about 0.9 km east of Crooked Creek in the SW¼NW¼ sec. 5, T. 32 S., R. 41 E. About 20 m of the upper, fine-grained member, including the upper marker tuff, is exposed at this stop (Figure 12). The upper marker tuff represents the top of the Rome beds at this locality, but drilling farther north of the highway by Anaconda Minerals Company (Santini and LeBaron, 1982) indicated that as much as 18 m of mudstone locally overlie the upper marker tuff. Grayish-brown mudstone and siltstone of Pliocene age unconformably overlie the upper marker bed at this stop, and basalt unconformably overlies the brown sediments. West of Crooked Creek,

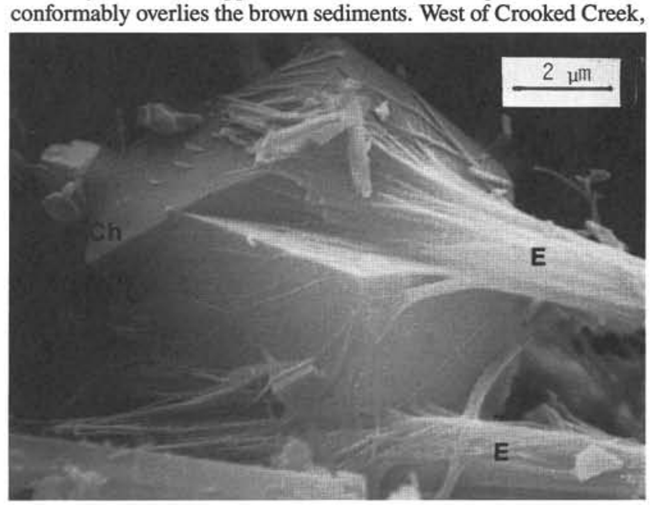

Figure 11. SEM of the lower marker tuff, Rome, Oregon, showing thin needles or fibers of erionite (E) *that grew on rhombohedral chabazite* (Ch).

Figure 12. Upper marker tuff at the second field trip stop (Stop 5 in Figure 6) at the Rome, Oregon, deposit on the north side of U.S. Highway 95, about 0.9 km east of Crooked Creek. The upper marker tuff consists of ledge-forming lower gray (L) *and middle orange* (O) *subunits and a less resistant upper gray* (U) *subunit. A greenish-gray, vuggy bed occurs in the upper third of the lower gray subunit. The upper marker tuff grades into the underlying tuffaceous mudstone.*

the basalt rests on a part of the Rome beds that is stratigraphically lower than the upper marker tuff. The mudstone beneath the upper marker tuff is gray to grayish green and is commonly concealed by a punky "popcorn" coating formed by weathering of expandable clay minerals in the mudstone. Thin beds of tuff, chert, and ostracodal limestone occur in the lower part of the upper, fine-grained member of the Rome beds. A distinctive chert, known as Magadi-type chert (Sheppard and Gude, 1974), crops out 7-8 m beneath the upper marker bed at this stop. Nodules of this chert that show characteristic surface reticulation (Figure 13) are appropriately called snakeskin agates by rockhounds and lapidaries.

The zeolitic upper marker bed forms a conspicuous ledge and is probably the most distinctive unit in the Rome beds. This marker tuff consists of three subunits that total 6-7 m in thickness. At this locality, the upper part of the tuff was eroded prior to deposition of the overlying Pliocene sediments. From drilling north of the highway, Santini and LeBaron (1982) suggested that the original thickness of the upper marker tuff was as much as 13 m. A resistant orange subunit near the middle of the marker tuff separates the

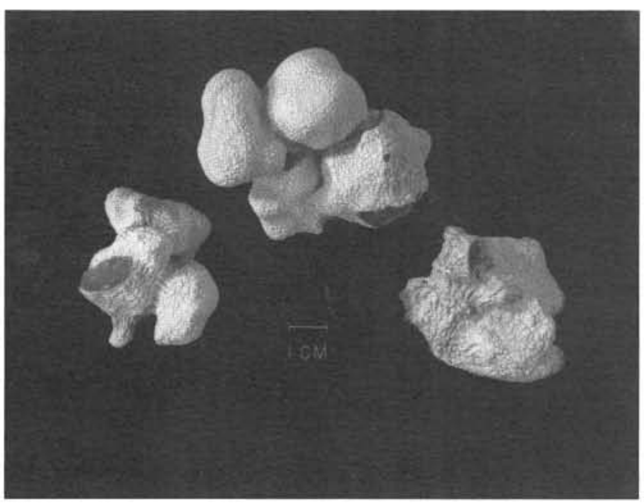

Figure 13. Small lobate nodules of Magadi-type chert (snakeskin agate) from Rome, Oregon, showing charateristic surface reticulation and thin white coating.

predominantly light-gray tuff into lower and upper subunits (Figure 12). Both gray subunits break with a blocky to conchoidal fracture and contain abundant crystal molds of gaylussite(?). A thin bed of greenish-gray, vuggy tuff occurs locally in the upper third of the lower gray subunit. The orange subunit is about 1 m thick and consists of a thin lower bed and a thicker upper bed (Figure 14). Both beds break with a hackly or irregular fracture and have contorted laminations in their basal parts.

The mineralogy (Table 3) of the upper marker tuff and underlying rocks of the upper, fine-grained member of the Rome beds at this stop was determined by study of XRD patterns of bulk samples. The mudstone consists mainly of authigenic constituents that formed from an originally high content of vitric material. Potassium feldspar and clay minerals predominate, but quartz, clinoptilolite, and erionite are locally obvious. Even the fluorite and some, at least, of the calcite in the mudstone are authigenic.

The upper marker tuff consists chiefly of authigenic zeolites, clay minerals, quartz, potassium feldspar, and locally minor fluorite, calcite, and opal C-T. The tuff originally consisted mainly of silicic glass shards and minor crystal fragments. Relict vitroclastic texture is well preserved in some parts of the tuff but is vague or absent in other parts. Unaltered glass was not recognized at this particular locality, but abundant unaltered glass occurs in parts of the upper marker tuff about 2.2 km south of this stop.

The zeolite mineralogy of the upper marker tuff (Table 3), though variable, shows a certain consistency with the subunits described above. Mordenite is the principal zeolite in the lower and upper gray subunits and is locally associated with minor clinop-

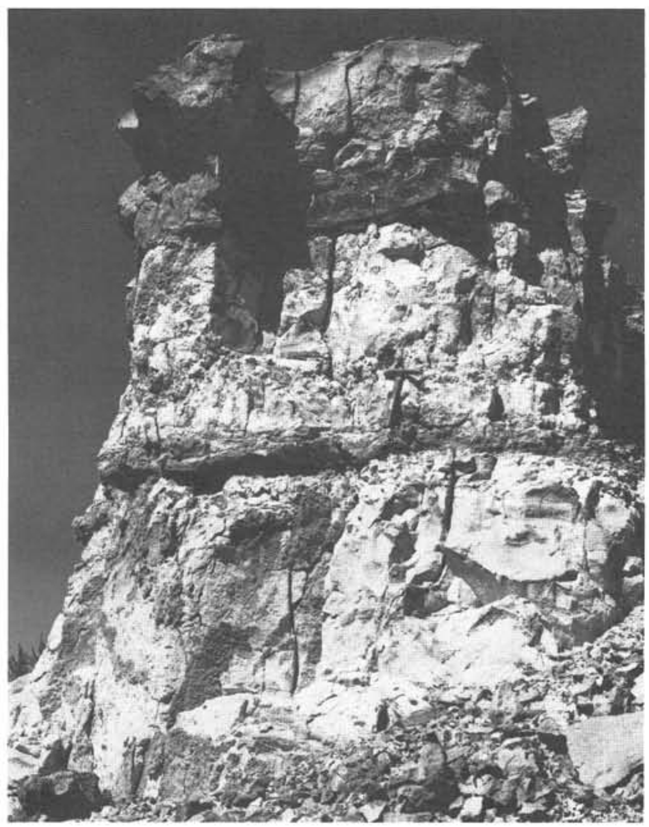

Figure 14. Upper marker tuff at the Rome, Oregon, zeolite deposit showing the lower gray subunit capped by the middle orange subunit. A distinctive greenish-gray vuggy bed occurs in the lower gray subunit beneath the hammer handle. The orange subunit splits into two beds. Mordenite is the principal zeolite in the lower gray subunit, but clinoptilolite, erionite, and phillipsite make up the orange subunit.

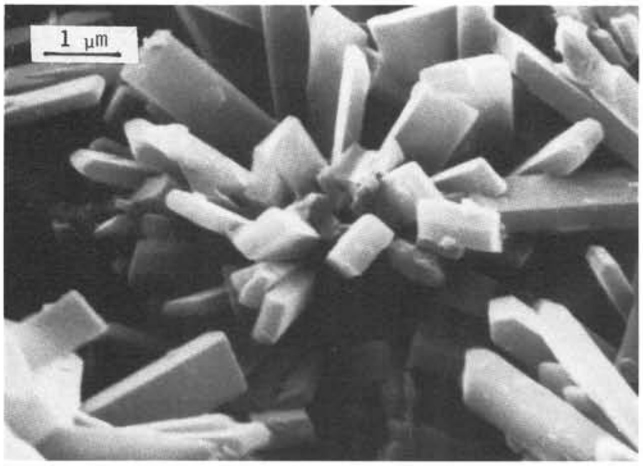

Figure 17. SEM of the basal part of the orange subunit of the upper marker tuff at the Rome, Oregon, zeolite deposit, showing a rosette of prismatic phillipsite.

Both high pH and high salinity of the pore water favor rapid solution of silicic vitric material (Surdam and Sheppard, 1978). Surdam and Sheppard (1978) indicated that the important chemical properties of the pore water during the reaction of glass to zeolites are as follows: cation ratios, Si:Al ratio, and the activity of H_2O. These properties are, of course, affected by changes in the salinity and/or alkalinity. The pH, in particular, influences the Si:Al ratio of the pore water and, thus, the Si:Al ratio of the zeolite that crystallizes from the pore water.

Campion (1979) showed that the authigenic potassium feldspar in the Rome beds formed from precursor zeolites as well as from clay minerals and detrital plagioclase. Although kinetic factors may be important for the zeolite to potassium feldspar reaction, high pH and high salinity of the pore water certainly favor the reaction.

Table 4. *Chemical composition of rhyolitic glass from the Rome beds.*[1]

SiO_2	72.44	MgO	0.10	CaO	0.46
Al_2O_3	11.26	K_2O	5.08	H_2O[2]	6.67
Fe_2O_3	1.14	Na_2O	2.85	Total	100.00

[1]Electron microprobe analysis from Campion (1979). Shards were separated from a tuff located in the SW1/4, SE1/4, Sec. 8, T32S, R41E (about 2.2 km south of Stop 5).
[2]Water calculated by difference.

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Released 12-30-86: *Geologic map of the northwest quarter of the Cave Junction quadrangle, Josephine County,* Geological Map Series GMS-38. ☐

Correction

In the October 1986 article on the Turner-Albright massive sulfide deposit (*Oregon Geology,* v. 48, no. 10, p. 117), the cobalt values in paragraph 2, line 17, should have read 0.05 percent cobalt.

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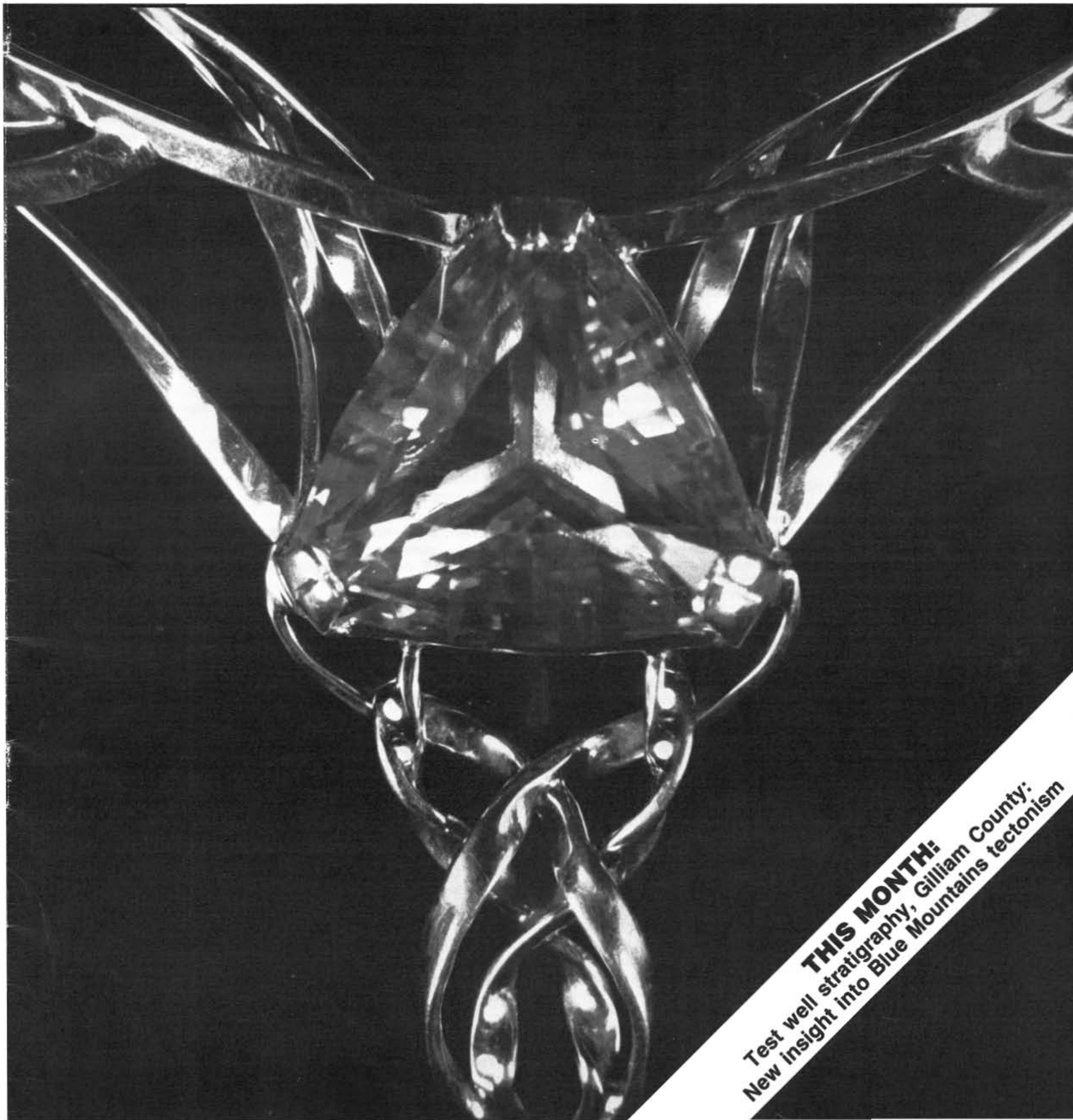

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Setting of an Oregon sunstone. Champagne-yellow, 10.25-carat gemstone from Lake County is owned by the Columbia-Willamette Faceters Guild. Triangular cut by Lois Schwier of Portland, Oregon; setting designed and made by Al Price, French's Jewelers, Albany, Oregon. See related article on sunstones beginning on page 23.

OIL AND GAS NEWS

Mist Gas Storage Project

Oregon Natural Gas Development is continuing to drill wells for the gas storage project, keeping two drilling rigs busy with injection and observation wells. The injection wells are drilled into the depleted Bruer and Flora pools and are completed with 8⅝-in. casing plus a liner through the gas zone. The observation wells are drilled similar to a conventional producing well but are located outside the limits of gas, to measure zone pressures by monitoring the formation waters.

Recent wells include OM 43c-3 in SE¼ sec. 3, T. 6 N., R. 5 W., drilled in December to 3,655 ft as an observation well. OM 41a-10 in NE¼ sec. 10, T. 6 N., R. 5 W., was also drilled in December to a total depth of 3,067 ft. January activity included the drilling of another observation well, OM 12c-3, in NW¼ sec. 3, T. 6 N., R. 5 W., as well as an injection well, IW 34d-3, in SE¼ sec. 3, T. 6 N., R. 5 W. Neither had reached total depth at the time of this writing. OM 12c-3 has a proposed total depth of 3,400 ft, while IW 34d-3 is projected for 2,800 ft.

Future gas storage drilling will include OM 14a-3 in SW¼ sec. 3, OM 32a-11 in NE¼ sec. 11, and OM 44d-3 in SE¼ sec. 3, all in T. 6 N., R. 5 W. □

Gorda Ridge symposium announced

A symposium on the research dealing with mineral exploration of the Gorda Ridge seafloor spreading center will be held May 11-13, 1987, in Portland, Oregon.

The symposium is sponsored by the Gorda Ridge Technical Task Force and will include plenary sessions and workshops on the following subjects:

- Gorda Ridge polymetallic sulfide discoveries.
- Exploration technologies for seafloor massive sulfides.
- Models of mineralization in modern hydrothermal systems.
- Comparative ecology of hydrothermal vent communities and nonvent communities.
- Genetic resources of hydrothermal vent communities.

Further plans may include a two-day field trip to an on-land massive sulfide deposit and a family-oriented trip to the Oregon coast.

For information, contact Greg McMurray, Marine Minerals Coordinator, Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 S.W. Fifth Avenue, Portland, Oregon 97201, phone (503) 229-5580. □

Oregon Academy of Science announces meeting

The Oregon Academy of Science (OAS) will hold its annual meeting for 1987 on Saturday, February 28, at Western Oregon State College (WOSC) in Monmouth.

The meeting will feature a special symposium on the topic "Could there be a devastating earthquake in Oregon?" Organizers of the symposium are R.S. Yeats, Department of Geology at Oregon State University, and D.A. Hull, State Geologist, Oregon Department of Geology and Mineral Industries.

Further information will be available soon from OAS secretary Susan Humphreys, WOSC. Abstract forms for papers may be requested from OAS Proceedings editors Claude Curran and John Mairs, Geography Department, Southern Oregon State College. □

Correction

The name of the previous Chair of the DOGAMI Governing Board was given incorrectly in last month's *Oregon Geology.* The name should have been Sidney R. Johnson of Baker. We apologize for this error. —*Editor*

Stratigraphy of the Standard Kirkpatrick No. 1, Gilliam County, Oregon: New insight into Tertiary tectonism of the Blue Mountains[1]

by T.P. Fox, ARCO Oil and Gas Company, Plano, Texas[2], and S.P. Reidel, Rockwell Hanford Operations, Richland, Washington 99352

ABSTRACT

This study integrates existing geologic knowledge of the Standard of California Kirkpatrick No. 1 with new data recently acquired in an attempt to detail the volcanic stratigraphy of the well. The Kirkpatrick No. 1 penetrated 2,440 ft of the Columbia River Basalt Group (CRBG), 4,255 ft of John Day and possibly Clarno volcanic rocks, and more than 2,000 ft of Mesozoic marine sedimentary rocks. This is the northernmost known occurrence of Mesozoic sedimentary rocks in Oregon. New isotopic dates for the John Day/Clarno(?) rocks and chemical compositions for these rocks and the Columbia River Basalt Group are reported.

The John Day/Clarno(?) sequence consists dominantly of tuffs and fine-grained sedimentary rocks, with about one-quarter of the total section consisting of lava flows. We consider a welded ash-flow tuff at a depth of about 6,100 ft to be correlative to the John Day member *a* basal ash-flow tuff. The remaining 560 ft of Tertiary rock may be a previously unrecognized unit of the John Day Formation or part of the Clarno Formation.

A John Day-age intrusion is present in the Mesozoic rocks and the Tertiary section below the ash-flow tuff. This intrusion possibly has affected the thermal maturity of the rocks and may be responsible for the general lack of datable microfossils in the well samples.

In the CRBG, we interpret that all four magnetostratigraphic units of the Grande Ronde Basalt are present. Picture Gorge and Prineville basalts are not present, although they are intercalated with the Grande Ronde Basalt less than 15 mi to the south. A small fault may cut the CRBG at 760 ft.

Comparison of the Kirkpatrick No. 1 data with the regional geology indicates that uplift of the Blue Mountains began in Clarno time and probably continues today. At least 5,300 ft of uplift has occurred relative to the Kirkpatrick area since deposition of the John Day member *a* tuff. This displacement is attributed to a fault or fault zone interpreted along the north flank of the Blue Mountains uplift.

INTRODUCTION

The Standard of California Kirkpatrick No. 1 was spudded on January 31, 1957, in the SW¼ sec. 6, T. 4 S., R. 21 E., near Condon, Oregon (Figure 1). This well is located north of the Blue Mountains uplift in the southern portion of the Columbia Plateau and is sited at the intersection of a northeast-trending anticline and a northwest-trending anticline. The latter structure shows evidence of strike-slip faulting (Swanson and others, 1981). The Kirkpatrick No. 1 penetrated 2,440 ft of the Miocene Columbia River Basalt Group (CRBG) and 4,255 ft of John Day Formation and possibly Clarno Formation rocks of early Tertiary age. It then was plugged and abandoned on June 22, 1957, at 8,726 ft in Mesozoic marine sedimentary rocks (Figure 2). Although the well is almost 30 years old, the section that was drilled is an important aid in deciphering the geologic history of north-central Oregon.

PREVIOUS STUDIES

The focus of most previous studies of the Kirkpatrick No. 1 has been the lithology and petroleum potential of the Mesozoic sedimentary rocks. These rocks consist of interbedded marine graywacke sandstones, siltstones, and dark-gray argillites. Argillite appears to dominate the sequence. The cuttings commonly have shiny surfaces, suggesting that low-grade metamorphism and/or intense shearing and faulting have affected the sequence. Microfossil and source-rock studies (ARCO letter from J.H. Wiese to H.M. Simpson, November 28, 1972, on file with the Oregon Department of Geology and Mineral Industries [DOGAMI]) indicate that the sedimentary rocks at 7,177-7,184 ft and 7,647-7,653 ft contain pollen of late Jurassic-early Cretaceous age and are mature for oil generation (see also Newton, 1979; Fisk, written communication, 1986). A "meager microfossil assemblage" in the rocks below 6,700 ft also implies this age assignment (Standard of California memo on file with the DOGAMI). Total organic carbon (TOC) contents of the sedimentary section are usually very low. Overall, the Mesozoic sedimentary rocks in the well appear to have marginal hydrocarbon potential, although other tests could be attempted in a more complete investigation.

The John Day/Clarno(?) sequence is immediately above the Mesozoic rocks and below the CRBG. It consists of 4,255 ft of varicolored tuffs and sedimentary rocks with interlayered basaltic to silicic lava flows. Outcrops of the John Day Formation are composed primarily of tuffs with local rhyolite and rhyodacite flows. The Clarno Formation, however, consists of basalt and andesite flows separated by mudflow deposits, saprolites, and thin sedimentary beds (Waters, 1954; Robinson, 1975). Plugs and irregular intrusions of andesite, dacite, and rhyolite are also common in outcrops. Identification of the John Day/Clarno boundary is difficult, even in outcrop, due to the lithologic diversity of the pre-CRBG volcanic rocks (Swanson and Robinson, 1968). Isotopic dating is often utilized to help distinguish the two volcanic units, the Clarno Formation ranging from about 55 to 40 million years (m.y.) (Fiebelkorn and others, 1983) and the John Day Formation from 37 to 19 m.y. (Robinson and others, 1984). Uncertainties in isotopic dates may be responsible for the apparent 3-m.y. gap between the two formations.

The John Day/Clarno boundary in the well is an important

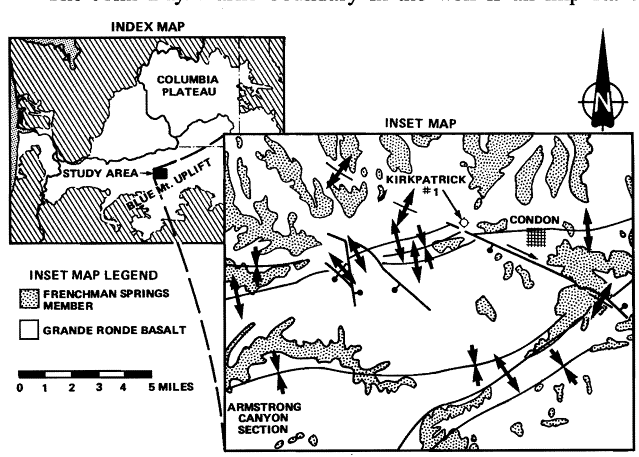

Figure 1. Location map of the Kirkpatrick No. 1. Geology modified from Swanson and others (1981).

[1]*Data summary of the research for this paper is available as Oregon Department of Geology and Mineral Industries Open-File Report O-87-2 (see Fox and Reidel, 1987).*

[2]*Present address: c/o Department of Geology, Colorado School of Mines, Golden, Colorado 80401.*

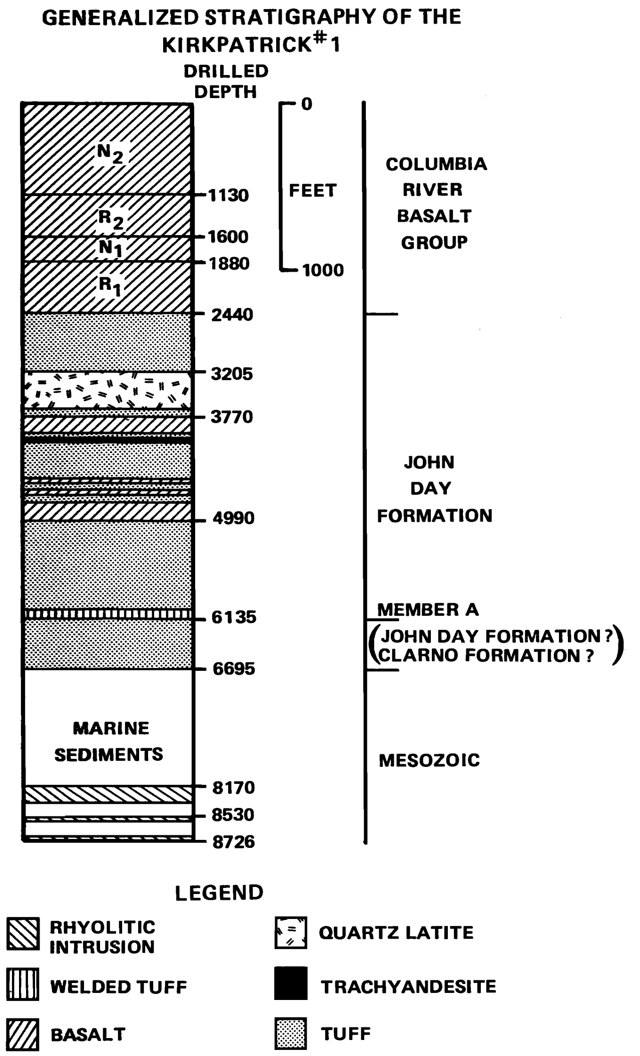

Figure 2. Generalized geology of the Kirkpatrick No. 1. See Fox and Reidel (1987) for detailed description.

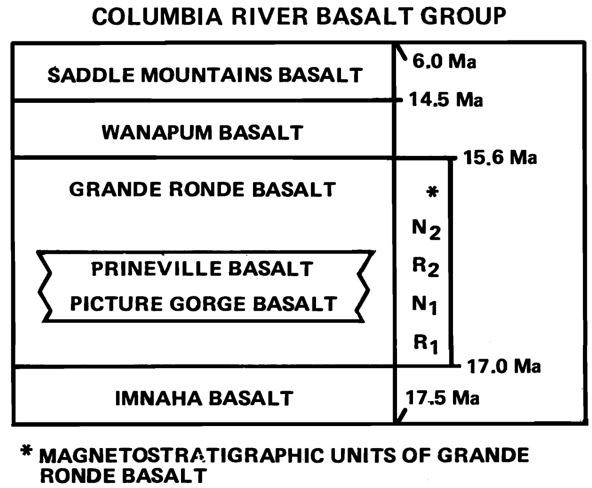

Figure 3. Columbia River Basalt Group stratigraphy. Modified from Swanson and others (1979); dates from McKee and others (1977, 1981) and Long and Duncan (1982).

horizon because its position in the well can provide critical subsurface structural information. Also, the thicknesses of the units can help in interpreting the early Tertiary paleogeography of the area. Wagner and Newton (1969) state that the top of the Eocene volcanics (Clarno) in the well is at a depth of 3,760 ft; however, the American Stratigraphic Company (1967) log for the well reports the contact is at 3,200 ft. The reasons for these identifications are unspecified, and no compositional or age data pertaining to this problem have been published.

The CRBG in Oregon, Washington, and Idaho consists of five formations (Figure 3). The Grande Ronde Basalt accounts for about 85 percent of the volume of the CRBG and consists of four magnetostratigraphic units: from younger to older, the N_2, R_2, N_1, and R_1 units (Swanson and Wright, 1976). The Kirkpatrick No. 1 was spudded in the N_2 magnetostratigraphic unit (Swanson and others, 1981) at a ground elevation of 2,747 ft. A total of 2,440 ft of basalt was drilled, placing the base of the CRBG at 307 ft above sea level. Prior to this study, the CRBG stratigraphy had never been described from the well; therefore, it was uncertain if R_2, N_1, R_1, or flows of the Picture Gorge or Prineville basalts had been penetrated. Regional mapping by J.L. Anderson (in Swanson and others, 1981) shows that R_2 and N_1 Grande Ronde Basalt, flows of the Prineville chemical type, and Picture Gorge Basalt are exposed within 15 mi southwest of the well.

The age of the Grande Ronde sequence is about 17.0 to 15.6 m.y. (McKee and others, 1977, 1981; Long and Duncan, 1982). Both the Picture Gorge Basalt and the Prineville chemical-type basalt are coeval with the Grande Ronde Basalt (Swanson and others, 1979) (Figure 3). Isotopic dating is of little use in distinguishing these basalts. Fortunately, Grande Ronde Basalt is compositionally distinct from Picture Gorge Basalt and flows of the Prineville chemical type (Wright and others, 1973; Swanson and others, 1979), although the magnetostratigraphic units within the Grande Ronde are not easily identified on the basis of composition (Swanson and others, 1979). Reidel (1983), however, demonstrated a correlation between chemical composition and magnetostratigraphy in the Grande Ronde Basalt in the Hell's Canyon area of northeast Oregon. This correlation provides a means of determining the magnetostratigraphy of the Grande Ronde Basalt in boreholes from which only chip samples are available.

METHODS

For this study, samples of the volcanic rocks in the Kirkpatrick No. 1 were taken at 20-ft intervals through the CRBG and at selected points through the pre-CRBG volcanic rocks. The 20-ft sampling interval in the CRBG provided means to determine the potential for vertical contamination during drilling and ditch-sample collection, as well as to evaluate the potential for repeated sections due to faulting. The samples were carefully handpicked to avoid obvious contamination and alteration and were then cleaned and analyzed for oxide compositions at Washington State University using the X-ray fluorescence method of Hooper and Atkins (1969). Isotopic dates were obtained from several cores in the John Day/Clarno(?) section using the potassium-argon (K/Ar) method on whole-rock or feldspar mineral separates from samples. Thin sections were also examined for petrologic relationships. All analytical data are summarized in Open-File Report O-87-2 (Fox and Reidel, 1987) and are on file with DOGAMI.

An examination of the CRBG well cuttings and the mudlog for weathered or vesicular basalt or soil zones provided an indication of the approximate locations of some of the basalt flow tops in the well. These imprecise depths were then correlated with compositional groupings of the basalts and with the geophysical logs from the well to separate flows and flow groups. Using chemical compositions (Table 1), we delineated the stratigraphy of the CRBG and compared it to that determined for the surrounding area by Swanson and others (1981) and for the Hell's Canyon area by Reidel (1983).

Geophysical logs from the well were examined to refine and

Table 1. *Chemical composition of Columbia River Basalt Group samples. All depths are in ft. All analyses are in weight percent. NS=not sampled.*

DEPTH	300-320	320-340	340-360	360-380	380-400
SiO_2	55.38	55.31	NS	55.40	55.40
Al_2O_3	15.06	15.63		15.10	15.23
Fe_2O_3	2.00	2.00		2.00	2.00
FeO	10.67	10.37		10.37	10.25
MgO	3.51	3.47		3.61	3.59
CaO	6.86	7.12		7.09	7.06
Na_2O	2.24	2.29		2.20	2.27
K_2O	1.53	1.17		1.50	1.49
TiO_2	2.23	2.13		2.19	2.19
P_2O_5	0.33	0.32		0.34	0.33
MnO	0.20	0.19		0.19	0.19

DEPTH	400-420	420-440	440-460	460-480	480-500
SiO_2	55.62	55.67	55.73	55.45	55.55
Al_2O_3	15.16	15.09	15.22	15.09	15.14
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.14	10.04	10.03	10.41	10.11
MgO	3.54	3.64	3.65	3.72	3.64
CaO	7.01	7.12	7.10	7.07	7.11
Na_2O	2.31	2.27	2.18	2.12	2.21
K_2O	1.55	1.58	1.55	1.61	1.68
TiO_2	2.14	2.08	2.05	2.04	2.06
P_2O_5	0.32	0.32	0.31	0.31	0.31
MnO	0.20	0.19	0.19	0.19	0.19

DEPTH	500-520	520-540	540-560	560-580	580-600
SiO_2	55.73	54.98	55.50	54.94	54.97
Al_2O_3	15.16	14.91	15.61	15.00	15.07
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	9.99	10.94	10.57	10.66	10.30
MgO	3.66	3.66	3.51	3.62	3.83
CaO	7.11	6.99	6.96	7.40	7.35
Na_2O	2.17	2.37	2.06	2.25	2.27
K_2O	1.59	1.43	0.94	1.38	1.53
TiO_2	2.08	2.19	2.38	2.21	2.16
P_2O_5	0.32	0.33	0.30	0.33	0.33
MnO	0.19	0.19	0.17	0.20	0.20

DEPTH	600-620	620-640	640-660	660-680	680-700
SiO_2	55.28	55.68	54.72	55.40	55.24
Al_2O_3	15.06	15.22	15.06	15.42	15.29
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.20	9.59	9.92	9.51	9.35
MgO	3.76	3.84	4.37	4.26	4.45
CaO	7.14	7.23	7.99	7.33	7.71
Na_2O	2.14	2.26	2.34	2.43	2.35
K_2O	1.78	1.63	1.26	1.31	1.27
TiO_2	2.11	2.05	1.88	1.92	1.87
P_2O_5	0.33	0.30	0.26	0.27	0.27
MnO	0.22	0.20	0.19	0.16	0.20

DEPTH	700-720	720-740	740-760	760-780	780-800
SiO_2	55.17	55.28	55.36	55.32	54.88
Al_2O_3	15.32	14.91	15.00	15.13	15.41
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	9.82	10.03	10.17	9.59	9.23
MgO	4.15	3.93	3.89	4.16	4.57
CaO	7.35	7.25	7.12	7.50	8.00
Na_2O	2.42	2.54	2.29	2.49	2.45
K_2O	1.34	1.52	1.55	1.43	1.23
TiO_2	1.96	2.02	2.12	1.90	1.78
P_2O_5	0.28	0.31	0.31	0.28	0.26
MnO	0.19	0.21	0.19	0.19	0.19

DEPTH	800-820	820-840	840-860	860-880	880-900
SiO_2	55.17	55.15	55.08	54.98	55.15
Al_2O_3	15.52	15.42	15.32	14.93	15.05
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	9.31	9.48	9.48	10.18	10.18
MgO	4.58	4.55	4.41	3.85	3.93
CaO	7.71	7.67	7.80	7.63	7.14
Na_2O	2.37	2.27	2.40	2.38	2.54
K_2O	1.18	1.21	1.24	1.45	1.44
TiO_2	1.74	1.80	1.82	2.08	2.06
P_2O_5	0.25	0.27	0.27	0.32	0.31
MnO	0.18	0.18	0.19	0.21	0.19

DEPTH	900-920	920-940	940-960	960-980	980-1000
SiO_2	54.44	54.70	54.37	55.34	55.11
Al_2O_3	15.02	15.06	14.88	16.02	14.95
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.26	10.48	10.95	10.22	10.34
MgO	4.17	4.08	3.98	3.48	3.78
CaO	7.59	7.35	7.14	6.81	7.11
Na_2O	2.63	2.33	2.48	2.23	2.54
K_2O	1.31	1.37	1.40	1.00	1.56
TiO_2	2.07	2.11	2.26	2.35	2.11
P_2O_5	0.31	0.32	0.34	0.38	0.32
MnO	0.19	0.19	0.20	0.17	0.19

DEPTH	1000-1020	1020-1040	1040-1060	1060-1080	1080-1100
SiO_2	55.02	55.09	55.33	55.06	54.90
Al_2O_3	15.15	14.90	15.05	14.90	15.04
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.22	10.65	10.42	10.41	10.51
MgO	3.92	3.80	3.66	3.74	3.86
CaO	7.16	6.96	6.76	7.09	7.04
Na_2O	2.46	2.36	2.51	2.58	2.53
K_2O	1.50	1.59	1.55	1.57	1.53
TiO_2	2.06	2.14	2.20	2.15	2.08
P_2O_5	0.31	0.32	0.32	0.32	0.31
MnO	0.19	0.20	0.19	0.19	0.19

DEPTH	1100-1120	1120-1140	1140-1160	1160-1180	1180-1200
SiO_2	55.78	54.55	56.22	55.68	57.10
Al_2O_3	15.26	15.11	15.06	14.99	15.38
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.44	11.04	10.15	11.16	9.95
MgO	3.30	4.00	3.06	3.18	2.71
CaO	6.29	6.70	6.32	6.19	5.66
Na_2O	2.32	2.41	2.36	2.27	2.43
K_2O	1.67	1.38	2.01	1.65	1.85
TiO_2	2.39	2.28	2.29	2.35	2.39
P_2O_5	0.34	0.34	0.34	0.34	0.36
MnO	0.20	0.20	0.19	0.20	0.16

DEPTH	1200-1220	1220-1240	1240-1260	1260-1280	1280-1300
SiO_2	56.56	56.66	55.00	54.87	54.58
Al_2O_3	15.20	15.27	15.00	15.05	14.94
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.07	9.88	10.34	10.33	10.66
MgO	2.96	2.78	3.68	3.81	3.78
CaO	6.15	5.91	7.02	7.13	7.16
Na_2O	2.37	2.62	2.32	2.44	2.46
K_2O	1.87	2.00	1.66	1.57	1.48
TiO_2	2.30	2.35	2.43	2.29	2.41
P_2O_5	0.35	0.36	0.34	0.32	0.34
MnO	0.17	0.17	0.21	0.19	0.20

DEPTH	1300-1320	1320-1340	1340-1360	1360-1380	1380-1400
SiO_2	55.11	54.82	54.50	54.96	55.43
Al_2O_3	15.17	15.17	15.07	15.32	15.86
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.04	10.42	10.58	10.47	10.10
MgO	3.85	4.03	3.72	3.69	3.00
CaO	7.17	7.12	7.16	6.81	6.37
Na_2O	2.40	2.33	2.29	2.32	2.59
K_2O	1.54	1.34	1.62	1.43	1.51
TiO_2	2.22	2.27	2.53	2.45	2.56
P_2O_5	0.32	0.31	0.34	0.34	0.41
MnO	0.19	0.18	0.20	0.21	0.17

DEPTH	1400-1420	1420-1440	1440-1460	1460-1480	1480-1500
SiO_2	55.79	54.48	NS	54.65	54.97
Al_2O_3	15.99	15.42		15.05	15.15
Fe_2O_3	2.00	2.00		2.00	2.00
FeO	9.84	10.51		10.61	10.36
MgO	2.68	3.67		3.56	3.40
CaO	6.22	7.01		6.97	6.76
Na_2O	2.60	2.35		2.53	2.62
K_2O	1.69	1.31		1.63	1.72
TiO_2	2.62	2.55		2.43	2.47
P_2O_5	0.42	0.40		0.36	0.36
MnO	0.17	0.28		0.20	0.18

DEPTH	1500-1520	1520-1540	1540-1560	1560-1580	1580-1600
SiO_2	55.19	54.76	NS	54.68	NS
Al_2O_3	15.13	15.01		15.14	
Fe_2O_3	2.00	2.00		2.00	
FeO	10.35	10.77		10.44	
MgO	3.61	3.59		3.72	
CaO	6.74	6.71		7.02	
Na_2O	2.33	2.48		2.45	
K_2O	1.66	1.67		1.59	
TiO_2	2.45	2.46		2.38	
P_2O_5	0.35	0.36		0.36	
MnO	0.19	0.19		0.21	

DEPTH	1600-1620	1620-1640	1640-1660	1660-1680	1680-1700
SiO_2	52.40	53.01	52.91	52.79	53.02
Al_2O_3	14.79	14.85	14.95	15.03	14.84
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.17	11.78	11.69	11.72	11.81
MgO	4.65	4.50	4.47	4.42	4.34
CaO	8.20	8.06	8.11	8.27	8.03
Na_2O	2.39	2.28	2.41	2.39	2.44
K_2O	0.65	0.79	0.73	0.69	0.79
TiO_2	2.18	2.17	2.17	2.13	2.17
P_2O_5	0.32	0.32	0.33	0.34	0.35
MnO	0.25	0.23	0.22	0.22	0.22

DEPTH	1700-1720	1720-1740	1740-1760	1760-1780	1780-1800
SiO_2	NS	52.59	52.22	51.74	51.86
Al_2O_3		14.64	14.75	14.77	14.74
Fe_2O_3		2.00	2.00	2.00	2.00
FeO		11.96	11.96	12.22	12.33
MgO		4.53	4.75	4.83	4.81
CaO		8.39	8.59	8.78	8.62
Na_2O		2.47	2.40	2.41	2.45
K_2O		0.73	0.64	0.50	0.50
TiO_2		2.12	2.13	2.20	2.16
P_2O_5		0.33	0.33	0.31	0.30
MnO		0.24	0.24	0.23	0.23

DEPTH	1800-1820	1820-1840	1840-1860	1860-1880	1880-1900
SiO_2	52.07	53.11	53.99	53.71	52.02
Al_2O_3	14.68	14.98	15.16	15.23	14.86
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.08	11.60	10.48	10.69	11.78
MgO	4.82	4.43	4.47	4.35	4.79
CaO	8.71	8.14	7.81	7.90	8.84
Na_2O	2.40	2.34	2.47	2.53	2.33
K_2O	0.56	0.75	0.98	0.97	0.55
TiO_2	2.14	2.14	2.12	2.09	2.29
P_2O_5	0.31	0.30	0.31	0.31	0.32
MnO	0.23	0.22	0.21	0.21	0.22

DEPTH	1900-1920	1920-1940	1940-1960	1960-1980	1980-2000
SiO_2	53.30	54.78	53.62	53.73	55.07
Al_2O_3	14.94	15.32	14.99	14.99	15.21
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	11.82	11.05	11.98	11.63	10.58
MgO	4.14	3.57	3.99	4.11	3.71
CaO	7.57	6.86	7.19	7.27	6.85
Na_2O	2.39	2.41	2.35	2.39	2.49
K_2O	0.91	1.20	1.03	0.97	1.17
TiO_2	2.34	2.28	2.30	2.37	2.38
P_2O_5	0.35	0.34	0.33	0.34	0.34
MnO	0.23	0.17	0.20	0.19	0.20

DEPTH	2000-2020	2020-2040	2040-2060	2060-2080	2080-2100
SiO_2	NS	NS	NS	52.78	51.87
Al_2O_3				15.02	14.61
Fe_2O_3				2.00	2.00
FeO				11.83	12.42
MgO				4.42	4.79
CaO				7.96	8.50
Na_2O				2.20	2.35
K_2O				0.92	0.59
TiO_2				2.32	2.31
P_2O_5				0.32	0.31
MnO				0.23	0.24

DEPTH	2100-2120	2120-2140	2140-2160	2160-2180	2180-2200
SiO_2	52.06	52.34	52.47	52.12	52.27
Al_2O_3	14.71	14.55	14.71	14.65	14.65
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.23	12.31	12.02	12.29	12.26
MgO	4.71	4.58	4.55	4.71	4.61
CaO	8.47	8.18	8.25	8.38	8.35
Na_2O	2.30	2.48	2.37	2.33	2.30
K_2O	0.67	0.76	0.82	0.69	0.74
TiO_2	2.29	2.28	2.28	2.29	2.29
P_2O_5	0.31	0.31	0.32	0.31	0.31
MnO	0.24	0.23	0.23	0.23	0.23

DEPTH	2200-2220	2220-2240	2240-2260	2260-2280	2280-2300
SiO_2	52.47	52.52	52.33	52.35	52.39
Al_2O_3	14.64	14.83	14.64	14.70	14.64
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.06	11.98	12.23	12.21	12.25
MgO	4.60	4.50	4.58	4.66	4.51
CaO	8.28	8.15	8.25	8.33	8.18
Na_2O	2.37	2.39	2.38	2.27	2.43
K_2O	0.78	0.80	0.76	0.69	0.75
TiO_2	2.26	2.28	2.27	2.25	2.30
P_2O_5	0.31	0.33	0.32	0.30	0.31
MnO	0.23	0.22	0.23	0.23	0.23

DEPTH	2300-2320	2320-2340	2340-2360	2360-2380	2380-2400
SiO_2	NS	NS	55.13	55.16	54.61
Al_2O_3			15.07	15.04	14.86
Fe_2O_3			2.00	2.00	2.00
FeO			10.97	10.74	11.27
MgO			3.44	3.45	3.51
CaO			6.77	6.89	6.90
Na_2O			2.35	2.45	2.43
K_2O			1.34	1.38	1.34
TiO_2			2.41	2.35	2.48
P_2O_5			0.34	0.34	0.38
MnO			0.19	0.20	0.22

DEPTH	2400-2420	2420-2440
SiO_2	55.04	54.61
Al_2O_3	14.95	14.64
Fe_2O_3	2.00	2.00
FeO	10.75	11.43
MgO	3.34	3.41
CaO	6.85	6.81
Na_2O	2.53	2.60
K_2O	1.41	1.37
TiO_2	2.51	2.50
P_2O_5	0.41	0.42
MnO	0.20	0.22

add to the basalt flow contacts interpreted from the cuttings and their compositions. Siems and others (1974) had used neutron logs to identify CRBG flow contacts in the central Columbia Plateau (Figure 4). Unfortunately, only spontaneous potential and resistivity logs had been run in the Kirkpatrick No. 1, because they were the principal logs in use at the time. Because the Kirkpatrick No. 1 resistivity log has the same response as the neutron logs in the CRBG (Figure 4), it was the only available log that made it possible for us to separate the solid, resistive flow interiors from the scoriaceous and weathered, fairly conductive flow tops and interbeds. A major problem with log interpretation is that fractured or vesicular zones within a flow can be mistaken for a flow contact. Also, during advance of the flow, the flow front may slow due to lateral spreading or the presence of slightly higher topography, and the flow may overtop itself, creating one or several flow lobes that may appear on the log to be individual flows. To avoid confusion, it is wise to use several logs, such as the sonic, neutron, and deep resistivity, and to look for a correlation in response between the logs.

The John Day and Clarno Formations are best identified by isotopic ages in combination with whole-rock compositions and petrology. The compositions of twenty samples of pre-CRBG igneous rocks from Kirkpatrick No. 1 are presented in Table 2. Four cores from a portion of the John Day/Clarno(?) section were dated using K/Ar methods on whole-rock samples and mineral separates (Table 3).

The resistivity log was useful in the John Day/Clarno(?) section for differentiating resistive lavas and intrusions from relatively conductive tuffs and sediments. Inferences from the logs were then checked with the available lithologic samples. The geophysical logs allowed fairly accurate depths to be assigned to lithologic changes so that the sample contamination by caving, which is probably common in the weaker tuffs, had minimal effect on lithologic description of the penetrated section.

RESULTS AND DISCUSSION

Mesozoic rocks

No research was conducted on the Mesozoic sedimentary rocks. Previous studies indicate that the microfossils are not well enough preserved to date these sediments more accurately, so we have adopted the previous assignment of these rocks as Mesozoic.

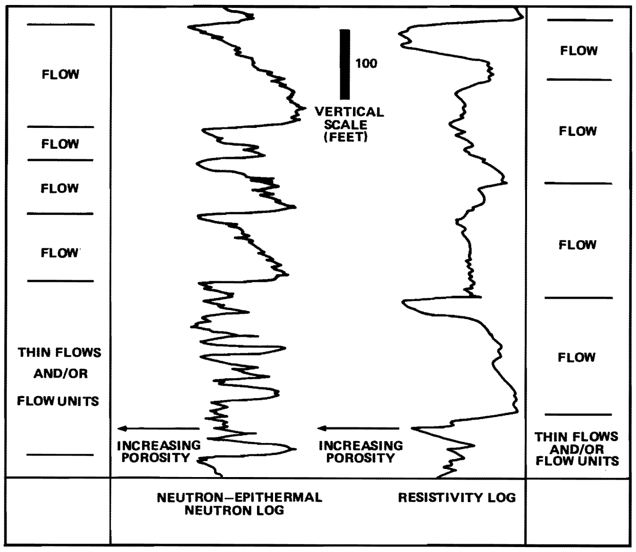

Figure 4. Response of neutron and resistivity logs to basalt flows. Neutron log from Siems and others (1974, Figure 5). Resistivity log from Kirkpatrick No. 1, showing weathered, fairly conductive flow tops and solid, resistive flow interiors and bottoms.

The Mesozoic rocks in the Kirkpatrick No. 1 were probably formed as deep-water turbidites, perhaps similar to the lower Cretaceous sedimentary rocks at Mitchell, Oregon (Kleinhans and others, 1984), the middle to upper Jurassic sedimentary rocks near Suplee, Oregon (Dickinson and Vigrass, 1965), or the undated rocks near Hay Creek and Muddy Ranch (Peck, 1964). The lack of preservation of microfossils in the well may be due to hydrothermal effects of the John Day-age intrusion, discussed in a later section.

The thermal alteration index (TAI) data determined by Fisk (written communication, 1986) and shown in Fox and Reidel (1987) indicate a relatively constant value of 2.7 from the base of the well to about 5,000 ft. Above this depth, the values decrease to a range of 1.8 to 2.0 to at least 1,440 ft. Some of the upper TAI values are slightly erratic, and Fisk attributes this to local thermal events such as volcanic flows, sills, and dikes. Reworking of organic material may also account for some of the erratic values. Fisk suggests the recorded thermal history is one of periodic major, though probably short-term, heating events but points out that there is a general increase in TAI values with depth.

John Day/Clarno(?) rocks

The John Day/Clarno(?) volcanic rocks occur from 2,440 ft to 6,695 ft in the Kirkpatrick No. 1, with a younger John Day-age rhyolite intrusion present in the lower part of the Tertiary section and in the Mesozoic section. The boundary between the John Day and Clarno Formations is transitional and cannot be picked unequivocally on the basis of either age or lithologic data, especially in borehole sections. The age of the earliest John Day deposit in north-central Oregon, a widespread ash-flow tuff named the "*a* member," has been determined to be 37.7±1.1 m.y. (Robinson and others, 1984). The youngest age for the Clarno Formation is about 40 m.y., but Clarno activity may have continued beyond 40 m.y. in some areas (P.T. Robinson, personal communication, 1986). From a petrologic standpoint, the uppermost occurrence of andesitic-basaltic lava flows in the Kirkpatrick No. 1 should mark the top of the Clarno Formation, because the John Day Formation is dominantly rhyolitic. However, the John Day Formation locally contains basalt flows near its base (Robinson and others, 1984), and the Clarno Formation contains some rhyolite flows and tuffs (Robinson, 1975). Fortunately, the John Day basalts tend to be more alkaline and have higher TiO_2 contents than Clarno basalts, thus providing a means to separate the two (Robinson, 1969).

Eight cores were recovered from the well, four of which have been dated (Table 3). Core 9 (8,268-8,278 ft) is a dense, white rhyolitic rock within the Mesozoic sedimentary section. The crystallinity, fresh appearance, and density of the rock suggest that the rock is not a tuff but instead a part of an intrusion. This interpretation is supported by a 28.8±1.2-m.y. age (John Day) that we believe to be correct. Also, similar rock was found and sampled both below core 9 and above it in the basal rocks of the Tertiary section. All of the samples are compositionally identical. No flows of correlative composition were found in the penetrated John Day section, however, indicating that this intrusion did not feed any flows encountered in the borehole.

The interpretation of the rhyolitic rock as a John Day intrusion is consistent with Fisk's (written communication, 1986) data. The beginning of the TAI decrease occurs across a thick basalt flow at 4,740-4,990 ft, and both the intrusive and the volcanics could be responsible for the elevated and erratic TAI values. One possible interpretation is that the TAI data in the lower part of the well may have been, in fact, elevated by thermal effects of a much larger unseen intrusion, of which core 9 is only a part. We can only speculate on this possibility.

The first dated sample above the Mesozoic sedimentary rocks

Table 2. *Chemical composition and CIPW normative minerals of the pre-Columbia River Basalt Group volcanics. All depths are in ft. All analyses are in weight percent. Q=quartz; Or=orthoclase; Ab=albite; An=anorthite; Di=diopside; Hy=hypersthene; Il=ilmenite.*

SAMPLE	1	2	3	4
DEPTH	2600-2680	2860-2900	3080-3140	3380-3400
	tuff	tuff	tuff	quartz latite
SiO_2	64.08	62.91	61.74	69.29
Al_2O_3	15.66	15.05	15.49	13.48
Fe_2O_3	3.93	3.78	4.17	2.73
FeO	4.50	4.33	4.78	3.12
MgO	1.97	2.15	2.20	0.62
CaO	5.11	5.77	5.62	2.98
Na_2O	2.96	2.34	2.38	3.42
K_2O	1.04	2.24	1.86	3.71
TiO_2	1.13	1.04	1.32	0.44
P_2O_5	0.23	0.22	0.27	0.08
MnO	0.15	0.17	0.17	0.12
Q	28.08	24.91	24.63	27.57
Or	6.15	13.24	10.99	21.93
Ab	25.05	19.80	20.14	28.94
An	23.86	23.94	26.09	10.47
Di	---	2.66	0.04	3.21
Hy	8.34	7.49	8.93	2.89
Il	2.15	1.98	2.51	0.84

SAMPLE	5	6	7	8
DEPTH	3460-3480	3580-3600	3700-3720	3820-3880
	quartz latite	tuff	tuff	basalt
SiO_2	70.00	77.32	68.87	48.94
Al_2O_3	13.69	12.74	14.36	15.91
Fe_2O_3	2.79	0.91	3.47	6.28
FeO	3.20	1.04	3.98	7.20
MgO	0.45	0.12	1.50	5.75
CaO	2.36	1.48	2.69	9.41
Na_2O	3.23	2.52	1.46	2.56
K_2O	3.59	3.63	2.24	0.56
TiO_2	0.50	0.19	1.23	2.81
P_2O_5	0.07	0.03	0.14	0.44
MnO	0.11	0.02	0.08	0.15
Q	30.60	45.10	43.03	5.66
Or	21.22	21.45	13.24	3.31
Ab	27.33	21.32	12.35	21.66
An	11.22	7.13	12.43	30.27
Di	---	---	---	10.79
Hy	4.07	1.18	6.30	12.86
Il	0.95	0.36	2.34	5.34

SAMPLE	9	10	11	12
DEPTH	4000-4020	4300-4360	4520-4540	4600-4640
	andesite	tuff	tuff	basalt
SiO_2	53.23	64.44	63.06	49.13
Al_2O_3	15.75	15.59	15.98	15.68
Fe_2O_3	5.89	4.21	4.92	6.00
FeO	6.74	4.82	5.63	3.87
MgO	3.46	1.75	1.96	5.48
CaO	7.85	4.55	2.95	9.14
Na_2O	2.71	1.64	1.49	2.88
K_2O	1.00	1.57	2.14	0.89
TiO_2	2.47	1.22	1.61	3.11
P_2O_5	0.74	0.09	0.18	0.64
MnO	0.16	0.13	0.08	0.19
Q	13.39	35.15	35.76	6.03
Or	5.91	9.28	12.65	5.26
Ab	22.93	13.88	12.61	24.37
An	27.86	21.98	13.44	27.23
Di	5.06	---	---	10.84
Hy	9.91	7.96	8.65	8.62
Il	4.69	2.32	3.06	5.91

SAMPLE	13	14	15	16
DEPTH	4740-4800	4940-4960	6080-6100	6300-6320
	basalt	basalt	tuff	rhyolite
SiO_2	50.92	50.84	73.93	78.67
Al_2O_3	15.62	15.40	12.78	13.35
Fe_2O_3	5.47	5.47	2.75	0.17
FeO	6.27	6.27	3.15	0.20
MgO	6.04	5.75	0.20	0.17
CaO	10.34	10.68	1.89	0.88
Na_2O	2.47	2.53	2.20	1.83
K_2O	0.42	0.34	2.25	4.62
TiO_2	2.02	2.23	0.61	0.04
P_2O_5	0.27	0.31	0.12	0.03
MnO	0.15	0.18	0.12	0.02
Q	6.91	7.18	47.27	48.20
Or	2.48	2.01	13.30	27.31
Ab	20.90	21.41	18.62	15.48
An	30.29	29.66	8.57	4.14
Di	15.32	16.95	---	---
Hy	11.69	9.90	3.23	0.62
Il	3.84	4.24	1.16	0.08

SAMPLE	17	18	19	20
DEPTH	6440-6460	8240-8300	8540-8600	8700-8725
	rhyolite	rhyolite	rhyolite	rhyolite
SiO_2	78.91	79.05	78.80	78.83
Al_2O_3	13.48	13.36	13.12	13.88
Fe_2O_3	0.23	0.18	0.29	0.21
FeO	0.26	0.20	0.33	0.24
MgO	0.07	0.00	0.00	0.00
CaO	0.63	0.87	0.90	0.44
Na_2O	1.94	2.10	3.08	2.38
K_2O	4.34	4.15	3.37	3.92
TiO_2	0.07	0.04	0.06	0.05
P_2O_5	0.04	0.03	0.03	0.03
MnO	0.03	0.03	0.03	0.03
Q	49.57	49.08	45.99	49.01
Or	25.65	24.53	19.92	23.17
Ab	16.42	17.77	26.06	20.14
An	2.86	4.10	4.27	1.99
Di	---	---	---	---
Hy	0.40	0.21	0.32	0.24
Il	0.13	0.08	0.11	0.10

Table 3. *K/Ar ages of volcanic rock cores.*

CORE	DEPTH	LITHOLOGY	AGE (m.y.)	DATED MATERIAL
#1	2737-2756	tuff	41.2 ± 4.5	feldspar
#2	4405-4422	tuff	36.6 ± 2.9	feldspar
#4	6542-6545	tuff	39.7 ± 1.7	whole rock
#9	8268-8278	rhyolite	28.2 ± 1.2	whole rock

is core 4, a dense, fine-grained, gray tuff recovered from 6,542-6,545 ft. An age of 39.7±1.7 m.y. indicates the tuff is probably a late Clarno equivalent. However, the uncertainty in age also allows assignment of the tuff to the John Day Formation.

Core 2 (4,405-4,422 ft) is a light gray-brown tuff. An age of 36.6±2.9 m.y. allows this tuff to be correlated to the basal John Day member *a* tuff and core 4.

Core 1 (2,737-2,756 ft) is also a light gray-brown tuff, but it contains micaceous flakes, suggesting the tuff was either reworked by streams or subject to alteration. The sample yielded a Clarno age of 41.2±4.5 m.y., which we consider to be a suspect date because the rock is then out of stratigraphic sequence. There appears to be no evidence of fault-repeated stratigraphy in the pre-CRBG section. Alternatively, we interpret the sample to be reworked or altered.

In summary, the best age data for the John Day/Clarno(?) sequence bracket the boundary age at 37 m.y. The dates are so close, however, that they cannot differentiate the John Day and Clarno Formations.

Whole-rock compositions were useful in grouping and identifying the pre-CRBG rocks in the Kirkpatrick No. 1. Cross, Iddings, Pirsson, and Washington (CIPW) norms (Table 2) were calculated for each sample, but we emphasize that the correlations suggested here are preliminary and should be confirmed with other techniques.

Samples 1, 2, 3, 6, 7, 10, and 11 (Table 2) are rhyolitic and dacitic air-fall tuffs, a lithology commonly assigned to the John Day Formation but not unknown in the Clarno Formation (Robinson, 1975). There appears to be no systematic compositional change coincident with stratigraphic position. Sample 6 has such a unique composition that it is almost certainly altered (Figure 5).

Samples 4 and 5 are from a 315-ft-thick quartz latite flow at 3,205 ft. This is the uppermost flow in the pre-CRBG sequence and probably was previously chosen as the top of the Clarno Formation for this reason.

Samples 8, 9, 12, 13, and 14 are intermediate and mafic lava flows. Sample 9 is compositionally similar to a trachyandesite, and the others are basaltic.

Based on petrologic data, the John Day/Clarno boundary should be placed at the top of the flow from which sample 8 was taken (3,765 ft), which is close to where Wagner and Newton (1969) placed it. However, as stated previously, the John Day basalts contain more than 2 percent TiO_2 by weight and are more alkaline than the Clarno basalts (Robinson, 1969). Figure 6 illustrates that samples 8, 12, 13, and 14 have a TiO_2 content more similar to basalts in the John Day Formation. Andesitic rocks (up to 62 weight percent SiO_2) and sample 9 have also been plotted for comparison. However, the samples were found to be low in alkalies relative to the John Day basalts. Recalculation of the compositions after adjusting the Fe_2O_3/FeO ratio to 0.25 (Robinson, 1969) has little effect on the total alkali composition of the samples. Why the basalts in the well have relatively low alkali contents in comparison to their TiO_2 contents is unclear; this may reflect minor alkali alteration of the samples. With this in mind, we view the SiO_2/TiO_2 data as more reliable and suggest that the basalt flows are part of the John Day Formation.

Sample 15 is a rhyodacitic ash-flow tuff stratigraphically between the units dated at 36.6 and 39.7 m.y. A thin section of the sample chips reveals crushed and welded pumice fragments in the chips. The composition of sample 15 is very similar to the average for the basal ash-flow tuff of member *a* in the John Day Formation (Figure 7). Departures from the average for calcium and sodium are not unusual; these two elements are highly mobile. In fact, Hay (1963)

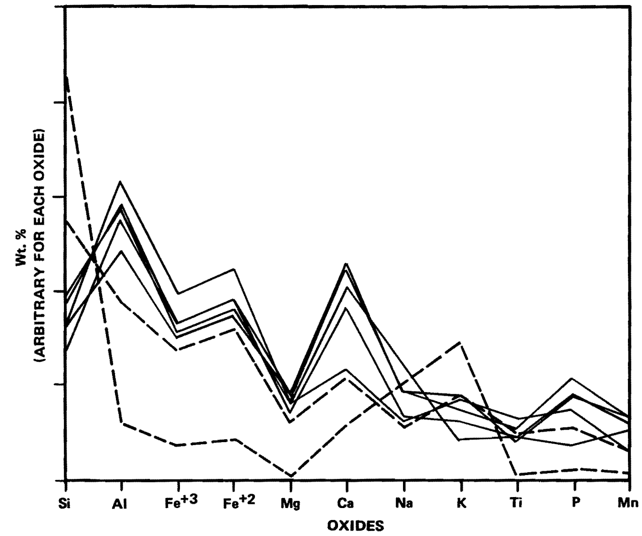

Figure 5. Comparison of oxide compositions of the air-fall tuffs from the John Day Formation. Samples 6 and 7 (dashed) are interpreted to show evidence of chemical alteration.

reports that the calcium content increases and the sodium content decreases in an altered John Day tuff, and our samples mimic this trend. The age determination is also consistent with the correlation. Therefore, a correlation of sample 15 to the basal ash-flow tuff of the John Day Formation seems reasonable.

If sample 15 is considered to be the base of the John Day Formation as recognized in outcrop, then the tuff in the Kirkpatrick No. 1 between 6,135 ft and 6,695 ft can either be considered a part of the Clarno Formation or a previously unrecognized unit within the John Day Formation. Based on the available data, we suggest that the tuff is a newly recognized unit of the John Day Formation, because air-fall tuffs are more common in this formation than in the Clarno. A detailed study of this unit is necessary to resolve this important stratigraphic problem.

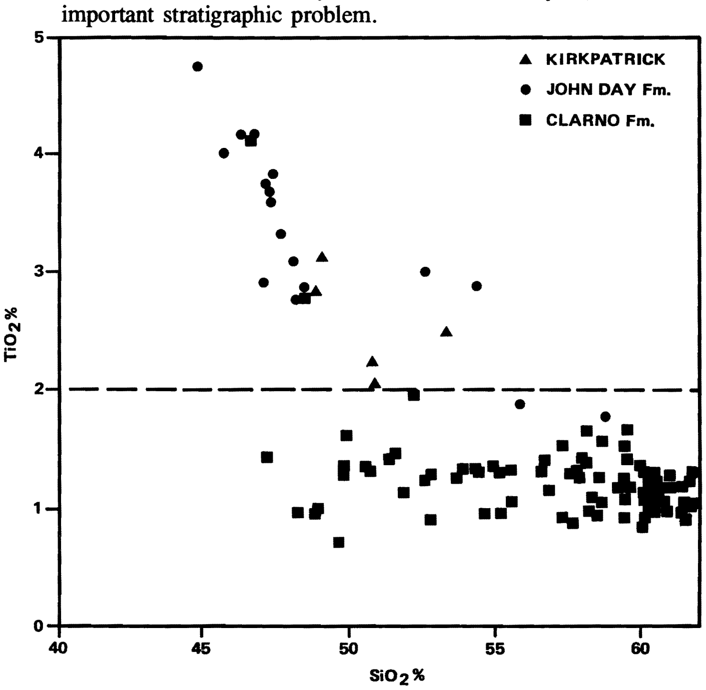

Figure 6. SiO_2/TiO_2 variation diagram for basalts and andesites exclusive of the Columbia River Basalt Group. Data from Robinson (1969) and Rogers and Ragland (1980).

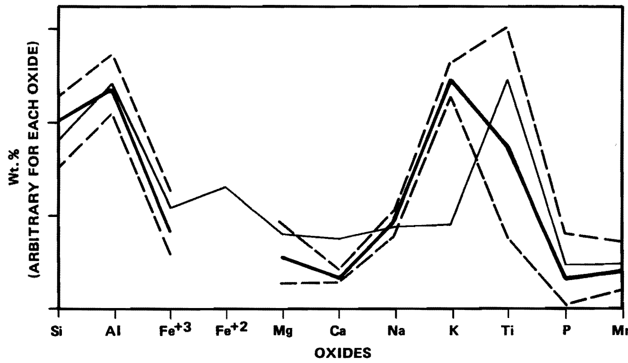

Figure 7. Comparison of sample 15 (solid line) to John Day member a *basal ash-flow tuff average (heavy line) and range (dashed lines). Data from Robinson (unpublished data, 1986).*

Samples 16 to 20 are all compositionally and lithologically similar to core 9, which was taken from the John Day-age rhyolitic intrusion in the Mesozoic sedimentary rocks. Based on the position of these samples, the intrusion is present in the Mesozoic sedimentary rocks and at least up to the lower part of the Tertiary section below the John Day member *a* correlative unit. We suggest that the intrusion has increased the TAI and corroded the microfossils in the sedimentary rocks below 5,000 ft in the well.

Any discussion of whole-rock composition needs to consider the effects of diagenetic alteration on the composition of the lavas. Diagenesis has obviously altered the air-fall tuffs (e.g., Hay, 1963), but compositional changes in the flows are not evident, except possibly for the alkalies to a minor extent. Samples 4 and 5 and samples 13 and 14 are dual samples that show nearly identical compositions within, respectively, a quartz latite flow and a basalt flow. This suggests no chemical alteration has occurred in the interior of these flows.

Columbia River Basalt Group

The Grande Ronde Basalt consists of four magnetostratigraphic units, the N_2, R_2, N_1, and R_1 units (Figure 3), that compositionally fall into two fields: low-MgO and high-MgO (Wright and others, 1973; Swanson and others, 1979). Reconnaissance field mapping of the CRBG in the Condon area by J.L. Anderson (in Swanson and others, 1981) shows that the Grande Ronde Basalt is the youngest CRBG unit present at the well site. Anderson's mapping identified at least three of the four Grande Ronde magnetostratigraphic units (N_2, R_2, and N_1) in the vicinity of the well.

Flows of the Prineville chemical-type basalt (Cockerham, 1974; Swanson and others, 1979; Smith, 1986) are intercalated with N_2 and R_2 Grande Ronde Basalt flows (J.L. Anderson, personal communication, 1986) west and south of the Condon area. In Armstrong Canyon, 12 mi southwest of the Kirkpatrick No. 1, a single Prineville flow is found at the base of the N_2 magnetostratigraphic unit (Figure 8). This flow has a distinctive composition that easily distinguishes it from the Grande Ronde Basalt.

South of the Condon area, Picture Gorge Basalt flows interfinger with and underlie the R_2 Grande Ronde Basalt (Cockerham, 1974; Swanson and others, 1981; Bailey, 1986). It is not known how far flows of the Picture Gorge Basalt extend north of the axis of the Blue Mountains uplift; however, vents and dikes of the basalt occur north of the axis. Previously, these vents and dikes were identified as part of the Grande Ronde Basalt (Swanson and others, 1981) but reexamination and analysis of them by Reidel and Tolan (unpublished data, 1986) shows that they are Picture Gorge Basalt.

The total thickness of the CRBG stratigraphy in the Kirkpatrick No. 1 is approximately 2,440 ft. Our interpretation of the geophysical logs indicates there are at least 25 flows (Fox and Reidel, 1987). Thicknesses of individual flows typically range from 50 to 80 ft but can be as great as 240 ft.

During the drilling of the Kirkpatrick No. 1, chip samples from the CRBG were collected at 20-ft intervals, beginning at 300 ft. Oxide compositions (Table 1) indicate that the entire CRBG section consists of Grande Ronde Basalt and that there are at least 16 compositionally distinct units. The shallowest samples collected are of a low-MgO/low- to intermediate-TiO_2 compositional type; this compositional type persists to 640 ft. From a depth of 640 to 1,130 ft, the basalts are of high- to intermediate-MgO/low-TiO_2 compositions. From 1,130 to 1,600 ft, the basalts are of low-MgO/high-TiO_2 compositions. High-MgO/high-TiO_2 flows occur from 1,600 to 2,310 ft, with the lowest flows having low-MgO/high-TiO_2 compositions.

The amount of mixing or contamination between samples from different flows during the drilling process is negligible. This conclusion is based upon several lines of evidence. First, the data in Table 1 (and Fox and Reidel, 1987) show no obvious mixing or gradational changes between basalt flows. All contacts are abrupt. Second, we can correlate compositionally distinct flows in the upper portion of the well to a surface section collected in Armstrong Canyon (Figure 8) (Reidel and Tolan, unpublished data, 1986). The compositions of these distinctive flows from the canyon to the well are virtually identical.

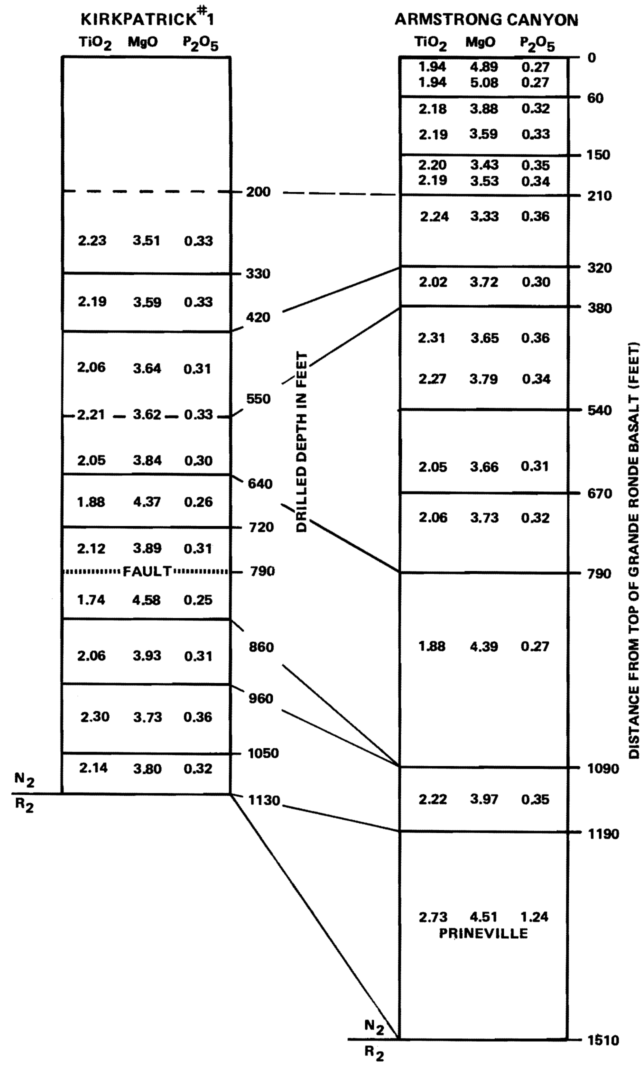

Figure 8. Comparison of TiO_2, MgO, and P_2O_5 for the N_2 section of the Columbia River Basalt Group between the Kirkpatrick No. 1 and the Armstrong Canyon section of Reidel and Tolan (unpublished data, 1986; see Figure 1).

All four of the Grande Ronde magnetostratigraphic units are probably present in the Kirkpatrick No. 1. The N_2 unit is defined by correlation of flow compositions from the well to Armstrong Canyon (Figure 8). The unit is about 1,190 ft thick in the canyon and 1,130 ft thick in the well.

A fault with less than 100 ft of offset is interpreted to be present at 760 ft in the N_2 magnetostratigraphic unit in the well. A low-MgO unit at 720-760 ft may be a repeat of a unit from 860-960 ft. Both are overlain by high-MgO units of similar composition (640-720 ft and 760-860 ft). At Armstrong Canyon and elsewhere in this area, this sequence of high- to intermediate-MgO/low-TiO_2 flows occurs only once in the N_2 unit. Nowhere in surface sections do we observe a repeat in compositions such as that in the Kirkpatrick No. 1. Therefore, the most likely explanation for what we see in the well is a fault repeating part of the N_2 section.

In the surrounding area, the R_2 magnetostratigraphic unit consists of a sequence of low-MgO/high-TiO_2 flows (Reidel and Tolan, unpublished data, 1986) that correlate to a depth of 1,130 to 1,600 ft in the Kirkpatrick No. 1. These flows are similar in composition to R_2 flows described by Reidel (1983) in the Salmon and Snake River area farther east.

The N_1 magnetostratigraphic unit typically consists of high-MgO/intermediate-TiO_2 flows intercalated with some high-TiO_2 flows (Reidel, 1983). The only N_1 flow exposed in the immediate area is of high-MgO/intermediate-TiO_2 composition. The composition of this flow resembles that of flows found from 1,600 to 1,880 ft in the well. The base of the N_1 unit is not exposed in the area, so the N_1-R_1 contact in the well is uncertain. The flow encountered from 1,880 to 2,000 ft may be of the N_1 high-TiO_2 "H" group flows of Reidel (1983), but this correlation is uncertain.

The flows of the R_1 magnetostratigraphic unit are dominated by high-MgO/high-TiO_2, making them distinctive among the Grande Ronde flows (Reidel, 1983). Basalt flows having compositions similar to the R_1 unit occur from 1,880 ft to the base of the basalt and are correlated to the R_1 unit.

The major difference between the basalt sequence in the Kirkpatrick No. 1 and the surrounding area appears to be the absence of Picture Gorge and Prineville flows and the thinning or disappearance of individual flows of the N_2 magnetostratigraphic unit. This suggests that the stratigraphic difference may be related to a combination of tectonic growth of the anticlines and the volume and origin of the individual flows. Data do not permit a distinction of the two at the present time. Based on interpretations from other parts of the plateau (e.g., Reidel, 1984), we suggest that tectonic growth of the structures may be the dominant factor controlling flow presence or absence.

Tectonic implications

The addition of the Kirkpatrick No. 1 stratigraphic data aids considerably in the paleogeographic interpretation of the north-central Oregon region for the early Tertiary. If the interpretations of this study are correct, the total John Day thickness in the well is 4,255 ft, compared to 1,750 ft in outcrop near Fossil (P.T. Robinson, written communication, 1986). Apparently, the John Day Formation has been eroded or preferentially not deposited on the Blue Mountains uplift, as previously suggested by Rogers (1966), Fisher (1967), and Swanson and Robinson (1968). Conversely, the Clarno Formation is 5,800 ft thick near Ashwood (Waters and others, 1951), thins to 3,000 to 4,000 ft near Clarno (Taylor, 1960), is less than 500 ft thick on Arbuckle Mountain southeast of Heppner (Shorey, 1976), and may be absent at the Kirkpatrick well site. This suggests that Clarno igneous activity was concentrated in the Blue Mountains uplift and did not extend significantly northward from this area.

The amount of uplift in the Blue Mountains can be approximated by the structural offset of the John Day member *a* ash-flow tuff. This tuff is at an elevation of 2,000 ft near the town of Fossil (Robinson, 1975), whereas in the well it is about 3,300 ft below sea level, suggesting that over 5,300 ft of uplift occurred in the Blue Mountains relative to the Kirkpatrick well (18 mi distant) in the last 37 m.y. This amount of uplift suggests a possible fault or fault zone that may coincide with a steep gravity gradient along the north edge of the Blue Mountains uplift (Riddihough, 1984; Riddihough and others, 1986).

The geologic data suggest a long period of uplift for the Blue Mountains during the Tertiary, beginning in the middle Eocene. Immediately prior to that time, the Blue Mountains area was not a topographic high. The Herren formation of Shorey (1976), a thick sedimentary unit of Paleogene age below the Clarno Formation around Arbuckle Mountain and elsewhere in the Blue Mountains, contains paleocurrent indicators suggesting northwesterly flow of streams across the axis of the Blue Mountains uplift (Trauba, 1975; Shorey, 1976; Gordon, 1985). During the remainder of the Eocene, the Blue Mountains became topographically high because of Clarno volcanism and probable structural uplift. By and during the Oligocene, the Blue Mountains were high enough to act as a topographic barrier to John Day ash flows erupted west of the uplift, causing thinning of the formation over the uplift (Robinson and others, 1984).

The Blue Mountains were still rising and the Columbia Basin was subsiding during the eruption of the CRBG, as shown by the thinning of the CRBG from the Kirkpatrick No. 1 to the north flank of the Blue Mountains uplift. The Blue Mountains have continued to grow since the Miocene. Grande Ronde N_2 and R_2 flows that were once continuous across the uplift have been eroded away, exposing the Mesozoic igneous core of the uplift (Swanson and others, 1981), and the N_2 and R_2 units have been turned to 30° dips off the north side of the uplift (Hogenson, 1964). The pinchout of Picture Gorge Basalt and Prineville basalt flows in the vicinity of the Kirkpatrick No. 1 is probably due to local structural control.

SUMMARY AND CONCLUSIONS

The pre-CRBG volcanic rocks penetrated in the Kirkpatrick No. 1 probably belong to the John Day Formation. Tertiary rocks below the tuff that correlates to the *a* member are interpreted as a newly identified unit of the John Day Formation. Alternatively, this unit may belong to the Clarno Formation, but a more detailed study of the unit is needed.

We have identified a John Day-age intrusion in the Mesozoic section and in the newly identified John Day unit. We suggest that the intrusion has increased the thermal maturation of the sedimentary rocks below 5,000 ft and also has caused a deterioration of microfossils. As a result, the oil-generation potential of the Mesozoic rocks in this area has been slightly overestimated, and the deterioration of microfossils has made it difficult for biostratigraphers to assign a definite age to the Mesozoic rocks.

By correlating the John Day member *a* welded ash-flow tuff from outcrop to its position in the well, we have determined that the Blue Mountains have been uplifted at least 5,300 ft relative to the well location in the last 37 m.y. This amount of structural relief over a relatively short distance indicates that a major fault is active on the north edge of the Blue Mountains uplift. An identified regional gravity lineament may coincide with this fault.

Chemical and magnetic stratigraphy of the CRBG section allows identification of basalt flow groups and even individual flows penetrated in the drill hole when these data are combined with geophysical logs. In the Kirkpatrick well, we conclude that every magnetostratigraphic unit of the Grande Ronde Basalt is present, despite the fact that the CRBG section is only 2,440 ft thick. No flows of the Picture Gorge Basalt or Prineville chemical type are present in the Kirkpatrick No. 1 basalt section. Thinning of the CRBG at the Kirkpatrick No. 1 location indicates that the area was a slight topographic high in the Miocene.

ACKNOWLEDGMENTS

We wish to thank ARCO Oil and Gas Company, Rockwell Hanford, and the U.S. Department of Energy for support of this study. Thanks also to Shell Western Exploration and Production for providing the dates for cores 4 and 9 and most of the thin sections. This manuscript has benefitted from reviews by P.T. Robinson, G.A. Smith, T.L. Tolan, and N.P. Campbell; however, the final content is our responsibility. Reidel was supported by the U.S. Department of Energy, contract no. DE-AC06-77RL01030, as part of the Basalt Waste Isolation Project.

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Standard Kirkpatrick well data released in open-file report

Stratigraphy of the Standard Kirkpatrick No. 1, Gilliam County, Oregon, by T.P. Fox, formerly of ARCO Oil and Gas Company, and S.P. Reidel, Rockwell Hanford Operations, presents details of lithology, contacts, electric logs, chemical composition, and isotopic ages from the well as an expanded stratigraphic column printed on a 30- by 55-in. ozalid sheet. The publication, which was released as Open-File Report O-87-2, was designed to supplement the data discussed in the paper beginning on page 15 of this issue.

Copies of Open-File Report O-87-2 are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $5. Orders under $50 require prepayment. □

Oregon sunstones

by Ronald P. Geitgey, Oregon Department of Geology and Mineral Industries

An exhibit of some of the mineral products of Oregon is on display on the main floor of the State Capitol Building until May. The exhibit, prepared by staff members of the Department of Geology and Mineral Industries, presents information on and examples of the production of natural gas, rare metals, gold, soapstone, industrial minerals, and gemstones. The centerpiece of the display is a collection of Oregon sunstone gems as unmounted, faceted stones and in finished pieces of jewelry, showing the full range of colors in which sunstone is found. The stones were mined in Lake and Harney Counties, cut by members of the Columbia-Willamette Faceters Guild, and set in gold mountings crafted by Oregon jewelers. *—Editor*

Oregon sunstone, also known as heliolite, is a transparent feldspar with colors ranging from water clear through pale yellow, soft pink, and blood red to (extremely rare) deep blue and green. The color appears to vary systematically with small amounts of copper and may depend on both the amount and the size of individual copper particles present in the stone. Pale yellow stones have a copper content as low as 20 parts per million (ppm) (0.002 percent), green stones contain about 100 ppm per million (0.01 percent), and red stones have up to 200 ppm (0.02 percent) copper (Hofmeister and Rossman, 1985). Some of the deeper colored stones have bands of varying color, and a few stones are dichroic, that is, they show two different colors when viewed from different directions.

Many stones appear to be perfectly transparent at first, but when they are viewed in just the right direction, a pink to red metallic shimmer flashes from within the stone. This effect is called "schiller" or "aventurescence" and is caused by light reflecting from minute parallel metallic platelets suspended in the sunstone. When viewed along their edges, the platelets are invisible to the naked eye; when viewed, however, perpendicular to their surfaces, they reflect light simultaneously from each platelet, creating a mirror effect. Earlier studies of the Lake County feldspar (Stewart and others, 1966) suggested that the platelets were hematite (iron oxide), but the most recent research concludes that they are flat crystals of copper metal (Hofmeister and Rossman, 1985).

The terms "sunstone" and "heliolite" (from Greek *helios*, meaning "sun," and *lithos*, meaning "stone") have been used for at least two centuries for feldspars exhibiting schiller. The Lake County occurrence was first reported in 1908 (Aitkens, 1931), and the presence of the schiller effect was the original reason for naming the stones sunstones. For decades, however, the term "sunstone" has been used for these Oregon gem feldspars both with and without schiller. The problems of nomenclature were reviewed by Pough (1983).

The Oregon sunstones are a calcium-rich variety of plagioclase feldspar named labradorite, a common mineral in basaltic lava flows. All three known sunstone occurrences shown on the index map (Figure 1) are in small basalt flows that superficially resemble basalt flows elsewhere in the state that contain large feldspar phenocrysts or megacrysts. However, feldspars in those flows are typically cloudy to opaque and relatively small compared to those in the sunstone flows, which are clear, glassy, and can be up to 2 or 3 in. in one dimension. No detailed information has been collected on the geology, petrography, or chemistry of the known sunstone flows, so no meaningful comparisons can be made between them or with other flows in the area. The sunstone flows appear to be small; the Lake County occurrence covers about 7 sq mi, and the two Harney County occurrences are probably less than 1 sq mi each. Considering the regional geology and the wide separation between the flows, it is probable that there are more sunstone occurrences in the area.

Sunstones are mined from the soil and partially decomposed rock formed by weathering of the lava flows. The surface debris is dug with pick and shovel and sieved through a quarter-inch screen, and the sunstones are separated from rock fragments by hand. In some local areas, the lava flows are weathered to a depth of several feet, and good stones have been recovered from pits dug into these zones. Hard-rock mining techniques have been used on unweathered parts of the flows, but the sunstones are often shattered along with the lava, and recovery of large unbroken stones is difficult.

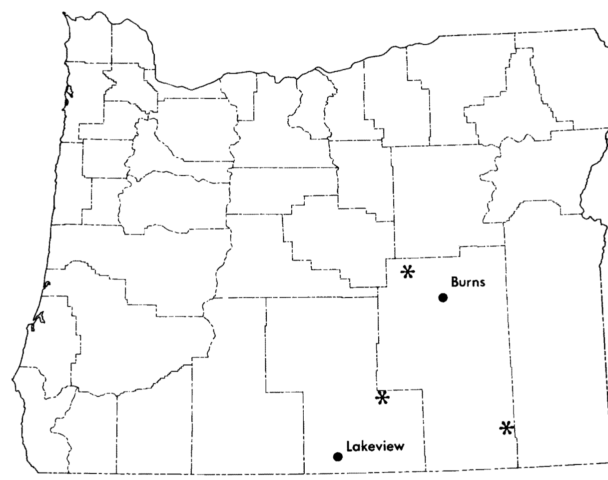

Figure 1. Index map of sunstone areas in Oregon.

Except for part of the Lake County occurrence, all three producing areas are held by mining claims and are not available for collecting without permission of the claim owners. About 2 sq mi of the Lake County flow have been withdrawn from mineral entry and established by the U.S. Bureau of Land Managment (BLM) as a free public collecting area. This sunstone area was described earlier by Peterson (1972) and is located off the northeast flank of the Rabbit Hills about 25 mi north of Plush and 80 mi northeast of Lakeview. Maps, directions, and information on road conditions are available from the BLM District Office in Lakeview.

Varieties of feldspars used as gemstones are valued for their colors or optical effects. Being typically translucent to opaque, they are normally cut in rounded forms or cabochons. Transparent gem feldspars, particularly calcium-rich varieties, that can be cut as faceted stones are rarer (Figure 2). Occurrences of transparent labradorite have been reported from Arizona, California, New Mexico, and Utah, but few gems have been produced from those areas. Oregon sunstones are uncommon in their composition, clarity, and range of colors, and they occur in sufficient abundance to permit sustained production of faceted gems.

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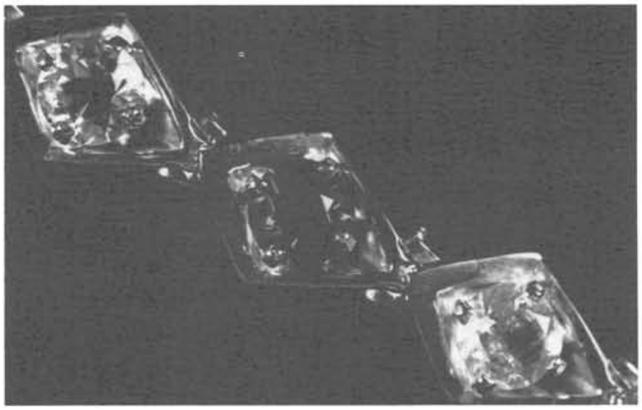

Figure 2. Section of bracelet composed of 16 one-carat, brilliant-cut sunstones from all three known deposits in Lake and Harney Counties. Colors include water clear, pale yellow, pink, and red. Stones cut by various members of the Columbia-Willamette Faceters Guild; gold setting designed and made by Al Price, French's Jewelers, Albany, Oregon. Bracelet was presented to the State of Oregon by the Oregon Retail Jewelers Association.

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State Map Advisory Committee publishes report for 1986

The State Map Advisory Committee for Oregon (SMAC) has released its eighth annual report: A summary of its activities and of the accomplishments and the current status of map production and coordination in Oregon for 1986.

The 55-page report was produced under the chairmanship of State Deputy Geologist John D. Beaulieu and published by the Oregon Department of Geology and Mineral Industries (DOGAMI) as Open-File Report O-87-1. It lists the members of the Oregon SMAC and its Subcommittee for Maps and Standards and the chairpersons of SMAC's in the other western states. The release further contains reports on SMAC meetings and work sessions; a report to the Regional Western Mapping conference held at Menlo Park, California; the 1986 annual report of the State Resident Cartographer; status reports on cooperation in digital base maps and standards; and a listing of the Committee's activities and accomplishments from 1979 through 1986.

The Oregon SMAC is an innovative committee consisting of representatives from Federal agencies, State agencies, local government, and private industry. Its purpose is to focus mapmaking activities in Oregon and to prevent duplication of mapping efforts. Over the years, the efforts of this committee have helped to bring millions of dollars into Oregon for mapping and map production in a coordinated fashion. The map product most familiar to the general public, the standard 7½-minute topographic map, is produced by the U.S. Geological Survey in cooperation with other agencies participating in SMAC. Other activities of the committee deal with computer mapping and a variety of other types of maps of various scales.

The new report, *Eighth Annual Report of the State Map Advisory Committee for Oregon, 1986*, is available now at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 S.W. Fifth Avenue, Portland, OR 97201. The purchase price is $5. Orders under $50 require prepayment. □

Geologic map of Cave Junction area, Klamath Mountains, released

A new geologic map released by the Oregon Department of Geology and Mineral Industries (DOGAMI) describes the geology of a portion of southwestern Oregon's old gold mining areas in the Klamath Mountains and the site of the rare mineral josephinite.

Geologic Map of the Northwest Quarter of the Cave Junction Quadrangle, Josephine County, Oregon, by staff geologist Len Ramp, has been published in DOGAMI's Geological Map Series as map GMS-38 and consists of two plates, each approximately 3½ by 2½ ft large.

The full-color map on Plate 1 (scale 1:24,000) includes the area of the Illinois River valley near Kerby and Cave Junction and the drainage of Josephine Creek to the west and is combined with an explanatory text. The map identifies 15 sedimentary, volcanic, and metamorphic rock units, most of them of Mesozoic and Paleozoic age (approximately 150 to 250 million years old). It also portrays the geologic structure, presents a geologic cross section, and identifies mines and mining prospects of the area. The text portion includes explanations of the rock units; a time-rock chart; a general discussion of the geologic setting, structure, and mineral deposits; and a table providing detailed information on the 26 mines and prospects identified within the area.

Plate 2 contains a sample-location map and four tables listing results of chemical analyses of 104 rock samples and of hand-panned concentrates from 70 stream-sediment samples.

Copies of the new map, GMS-38, are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $6. Orders under $50 require prepayment. □

DOGAMI display featured at Capitol Building

As part of its fiftieth anniversary celebration, the Oregon Department of Geology and Mineral Industries is presenting a display, Minerals and Metals in Oregon's Economy, at the State Capitol in Salem. The exhibit has been installed in the display case donated to the State in 1983 by the Oregon Council of Rock and Mineral Clubs.

Two necklaces and a bracelet containing faceted Oregon sunstones (see cover photo and article on sunstones in this issue) are featured in the center of the display case. Included in the display case are specimens of other faceted and unfaceted Oregon sunstones, gold, various industrial minerals, soapstone, and rare metals including titanium. The case also contains a sample of core from the Clark and Wilson sandstone, the reservoir rock at the Mist Gas Field.

The display was installed in mid-January and will remain in place until mid-May. □

Students win awards at NMA convention

A Washington State University student presented the most outstanding research paper at the Northwest Mining Association (NMA) convention in Spokane in early December 1986.

Jeffrey W. Brooks took home a Hewlett-Packard calculator, the top prize in NMA Student Poster Session. His paper was entitled "Mineralogy, Paragenesis, and Fluid Characteristics of the Mammoth Revenue Epithermal Au-Ag Vein."

"The Geology and Mineralization at the Champion Mine: An Epithermal Au-Base Metal System in the Bohemia Mining District, Oregon," earned $75 for University of Oregon student Kurt T. Katsura. □

New studies reveal details on sea-floor hydrothermal activity

Two reports on studies of materials obtained from the ocean floor at the Gorda Ridge and nearby seamounts have been released by the Oregon Department of Geology and Mineral Industries (DOGAMI). They are part of the continuing investigations conducted under the auspices of the Gorda Ridge Technical Task Force to evaluate the environmental, engineering, and economic aspects of possible leasing of polymetallic minerals on Gorda Ridge, a sea-floor spreading center off the coast of southern Oregon and northern California that lies within the U.S. Exclusive Economic Zone (EEZ).

Hydrothermal precipitates from basalts on the Gorda Ridge and the President Jackson seamounts, by K.J. Howard and M.R. Fisk of the Oregon State University College of Oceanography, has been published as DOGAMI Open-File Report O-86-18. The 30-page report presents analyses of precipitates that were deposited on rocks on the ocean floor at or near the sites of hydrothermal activity on the Gorda Ridge and the nearby seamounts.

Analysis of the samples in this study shows these deposits to be primarily hydrothermal clays and iron-manganese oxides. Minor amounts of sulfides, and possibly sulfates, arsenides, or arsenates, may be present in some samples.

While the greatest concentration of hydrothermally produced massive sulfides is found in the so-called "chimneys" at the center of major vents in the ocean floor, similar precipitates are found in a wide area around them. Identification of these minerals could point the way to active hot springs and associated massive sulfide deposits. Such deposits may also be economically important because of the wide range of elements that are dissolved in the hot water and their potentially large areal extent.

Sediment studies on the Gorda Ridge, by R. Karlin and M. Lyle, oceanographers from the University of Washington and Oregon State University, respectively, has been released as DOGAMI Open-File Report 0-86-19. The 76-page report presents sediment studies of seventeen gravity cores taken from the Gorda Ridge, including lithologic, magnetic, and chemical data.

The authors conclude that recent volcanic activity and related hydrothermal activity can be discerned and dated by analyzing sulfide-rich tuffaceous flow deposits and sulfur from plume material preserved in the sediments. They estimate occurrences of recent volcanic activity about 2,400 and 3,000 years ago at two volcanic centers in the southern end of the Gorda Ridge area.

Both open-file reports are available now at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201. The purchase price for each report is $5. Orders under $50 require prepayment. □

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that we feel are of general interest to our readers.

GEOLOGY OF THE NORTHWEST ONE-QUARTER OF THE PRINEVILLE QUADRANGLE, CENTRAL OREGON, by David J. Thormahlen (M.S., Oregon State University, 1984)

The northwest one-quarter of the Prineville quadrangle is underlain by Tertiary and Quaternary volcanic and volcaniclastic rocks of the Columbia River Basalt Group, and the Clarno, John Day, Rattlesnake, and Deschutes Formations.

The Clarno Formation is dominated by pyroxene-bearing andesites but also contains olivine-bearing basalts, oxyhornblende-bearing dacite and rhyodacite flows, and intrusives. Many of these rocks are deeply weathered, and some have been strongly silicified.

The John Day Formation in the area consists of large rhyolite domes and flows, thick tuffaceous deposits, minor trachyandesite flows and welded ash-flow tuffs. The stratigraphy of these John Day rocks is similar to the section exposed in the Ashwood area but lacks some of the upper ash-flow tuff units. Fossil-bearing tuffs found within the area are similar to tuffs in the John Day and Crooked River basins and contain fossil leaves that are similar to the Bridge Creek flora.

A single flow of the Columbia River Basalt Group is found in the southwest part of the thesis area. This flow has normal magnetic polarity and is similar to the Prineville chemical-type basalt. The entablature of this flow is glassy and very thick. It resembles exposures found at Butte Creek and along the Deschutes River at Pelton Dam and near Gateway.

Exposures of the Rattlesnake ignimbrite tongue in the northwest part of the thesis area are the westernmost recognized outcrops of the ignimbrite. Two other exposures of the Rattlesnake ignimbrite were found to the south in Swartz Canyon and near Little Bear Creek. These exposures indicate a previously unrecognized channel for the ignimbrite that trended northwest from its source, entered the Crooked River drainage, and traveled at least as far northwest as Grizzly.

The Deschutes Formation is represented by a diktytaxitic basalt flow, epiclastic tuffaceous sediments, and air-fall pumice. These deposits lie along the eastern margin of the Deschutes Basin.

Structural upwarping along the Blue Mountains anticline has caused local tilting and folding of the rocks in the area. Most of the Clarno and John Day rocks dip gently to the south. The Deschutes Formation appears to be undeformed.

Hydrothermal activity led to the formation of several mineralized breccias that contain abundant silica, lesser amounts of goethite and manganite, and traces of silver and mercury.

THE STRATIGRAPHY, GEOCHEMISTRY, AND MINERALOGY OF TWO ASH-FLOW TUFFS IN THE DESCHUTES FORMATION, CENTRAL OREGON, by Debra May Cannon (M.S., Oregon State University, 1985 [thesis compl. 1984])

Two ash-flow tuff units of the upper Miocene-lower Pliocene Deschutes Formation in central Oregon were studied in detail because of the widespread distribution, diverse compositions, and stratigraphic importance.

The Lower Bridge tuff is a double-flow simple cooling unit that is poorly welded. The upper flow grades from rhyolite in the lower part to dacite in the upper part. A white 1.5- to 5-ft accretionary lapilli air-fall deposit often underlies the two ash-flow sequences. Phenocrysts in the pumice lumps are plagioclase (An_{35-45}), pargasite, hypersthene, augite, ilmenite, apatite, and magnetite. The compositional change from rhyolite to dacite in the upper flow suggests that it was formed by eruption of successively lower parts of a zoned magma body.

The McKenzie Canyon tuff is a multiple flow compound cooling unit that overlies the Lower Bridge tuff. It may have covered 160 km^2 and had a volume of 0.7 km^3. It was erupted onto irregular terrain resulting in variable thicknesses. Up to three light-colored, rhyolitic ash-flow deposits are overlain by two red columnar-jointed units. The red color and welding of the upper two members are the distinguishing physical features of the McKenzie Canyon tuff. The lower nonresistant silicic flows are often absent in the northern part of the study area. The facts that the units decrease in thickness and in elevation northward and that the average pumice size becomes smaller suggest a source to the south. Another distinguishing feature of the upper red flow(s) is the prevalence of white (rhyolite), black (andesite), banded (rhyolite and andesite), and collapsed pumices. A few dacite pumice clasts (mixed) are also present. In the lower silicic flows, black or banded pumices are found only in minor amounts, and collapsed pumices are absent. Collapsed pumices in the upper flow(s) occur only throughout the welded section in nearly horizontal orientations.

The white pumice is a high-K rhyolite with phenocrysts of oligoclase/andesine (An_{29-31}), hypersthene, augite, magnetite, ilmenite, and zircon. The black pumice is medium-K and high -Ti and -Fe andesite that contains labradorite (An_{60-65}), olivine (Fo_{82}), augite, hypersthene, and magnetite. The percentage of black pumice increases upward in the upper flow. Banded pumice is a combination of rhyolite and andesite magmas and represents the co-eruption of these two compositions. Evidence of complete mixing of the magmas, i.e., homogeneous dacite pumice, is minor. Collapsed pumices have the same composition as rhyolite or banded pumices.

The McKenzie Canyon tuff was possibly derived from two separate magmas. As mafic magma was injected into a silicic magma chamber, ensuing convection and vesiculation probably caused the formation of banded pumice. This hypothesis is based on the following relationships: (1) phenocrysts and bulk chemistry of rhyolite and andesitic pumices are of distinct compositions, (2) a paucity of phenocrysts occurs in the andesitic pumices, and (3) Harker diagrams of major element chemistries show that the two magmas have divergent regression lines.

The McKenzie Canyon tuff upper flows are unusual among banded pumice-bearing tuffs because of the aphyric nature of the andesite and the probability that the rhyolite and andesite magmas are not derived from the same magma chamber.

THE DESCHUTES FORMATION — HIGH CASCADE TRANSITION IN THE WHITEWATER RIVER AREA, JEFFERSON COUNTY, OREGON, by Gene M. Yogodzinski (M.S., Oregon State University, 1986 [thesis compl 1985])

The Whitewater River area is located directly east of Mount Jefferson in the Cascades of central Oregon. Approximately 90 mi^2 (230 km^2) were mapped (scale 1/24,000), and four new K-Ar ages and 151 major-element analyses were obtained in a study of the stratigraphic and magmatic transition from the Miocene-Pliocene Deschutes Formation on the east to the Pliocene-Pleistocene High Cascades on the west.

Deschutes strata in the Whitewater River area overlie andesites, dacites, and rhyodacites of late Miocene age (8-11+ m.y.) along an erosional unconformity. The oldest Deschutes rocks exposed in the Whitewater River area are approximately 6 m.y. old, and the youngest are probably between 4.5 and 5 m.y. old. The oldest High Cascade rocks exposed in the Whitewater River area are approximately 4.3 m.y. old. There is no evidence for a hiatus in volcanic activity between Deschutes and High Cascade time in the Whitewater River area. Late Pleistocene explosive volcanism, probably from Mount Jefferson, is evidenced in a hornblende rhyodacite pyroclastic-flow deposit that occurs within the glacial stratigraphy and is tentatively thought to be between approximately 60,000 and 20,000 years old.

Deschutes strata are dominated by pyroclastic lithologies (mostly ash-flow tuffs), with some lava flows and minor epiclastic sediment. Compositions range mostly between basaltic andesite and dacite. Many Deschutes-age rocks are aphyric; high in FeO, TiO_2, and alkalies; and low in MgO, CaO, and Al_2O_3. They define a tholeiitic trend extending at least from basaltic andesite to dacite that can largely be derived through fractional crystallization of plagioclase, olivine, magnetite, and clinopyroxene from a parent magma, probably of basaltic composition. These rocks are compositionally similar to "tholeiitic anorogenic andesites" that are most commonly associated with areas of crustal extension.

Rocks of High Cascade age in the Whitewater River area are mostly lava flows that range in composition from basalt (high-alumina, olivine tholeiite) to rhyodacite. The High Cascade suite forms a calc-alkalic associaton that is typical of subduction-related magmatic arcs. Fractional crystallization of the basalts leads to iron enrichment. Fractional crystallization of the basaltic andesites might lead to calc-alkalic compositions, but the mineral phases necessary to deplete the magmas in FeO, TiO_2, and CaO (magnetite and clinopyroxene) are not common phenocryst phases in the basaltic andesites or andesites.

Two northwest-trending, down-to-the-west normal faults with some possible strike-slip motion have been mapped in the upper Whitewater River area, directly west of Lion's Head. Motion on these faults occurred after approximately 4 m.y. ago but probably began prior to that time. There is between 200 and 400 ft (60 and 120 m) of apparent vertical separation on the western side of these faults. There may be a large, northwest-trending fault running from the south end of Green Ridge through Bald Peter and the Whitewater River area, but this structure is largely buried by younger volcanic rocks. There is no evidence for a northern extension of the north-trending Green Ridge faults, and there is no evidence for large structural displacement in the lower Whitewater River along north- or northwest-trending structures.

The Deschutes Formation-High Cascade transition in the Whitewater River area is marked by a switch in the eruptive style and in the dominant magmatic compositions during Deschutes and High Cascade times. Volcanism in the Whitewater River area does not appear to have been episodic with respect to volume and/or intensity; rather, the character of magmatism has varied with time and with the tectonic style through the period immediately prior to and following the formation of the High Cascade graben.

GEOLOGY, ALTERATION, AND MINERALIZATION OF A SILICIC VOLCANIC CENTER, GLASS BUTTES, OREGON, by Michael J. Johnson (M.S., Portland State University, 1984)

Glass Buttes, a Pliocene silicic volcanic complex within the High Lava Plains province of Oregon, was erupted approximately 5.0 to 5.8 million years ago. Geologic mapping revealed that the eastern portion of the complex is underlain by rhyolitic glass domes, flows, and rare pyroclastic flows. Basalt flows are interlayered with and onlap the silicic glass. Younger basalt flows, erupted from local vents, overlie silicic glass and onlapping basalts.

The eastern end of Glass Buttes is hydrothermally altered at the surface; a weak geothermal anomaly coincides with the altered areas. Alteration, localized by northwest-trending normal faults, occurs primarily as opalite replacement of rhyolite glass with associated cinnabar, alunite, clay-rich vein material, hematite, and hyalite. Alteration paragenesis at the surface was defined, and physicochemical conditions during hydrothermal activity were inferred from alteration minerals and assemblages and trace-element content of alteration minerals.

Alteration identified in the subsurface is interpreted to be related to an older hydrothermal system. Carbonate, pyrite, quartz, and minor smectite and chlorite occur in vugs and fractures and partially replace subsurface basalt. Abundant fine-grained disseminated pyrite occurs in permeable units. Pyrite separates from disseminations and veins within basalt and permeable glassy units contain up to 13 ppm Au. The pyrite samples are also anomalous with respect to arsenic and antimony. □

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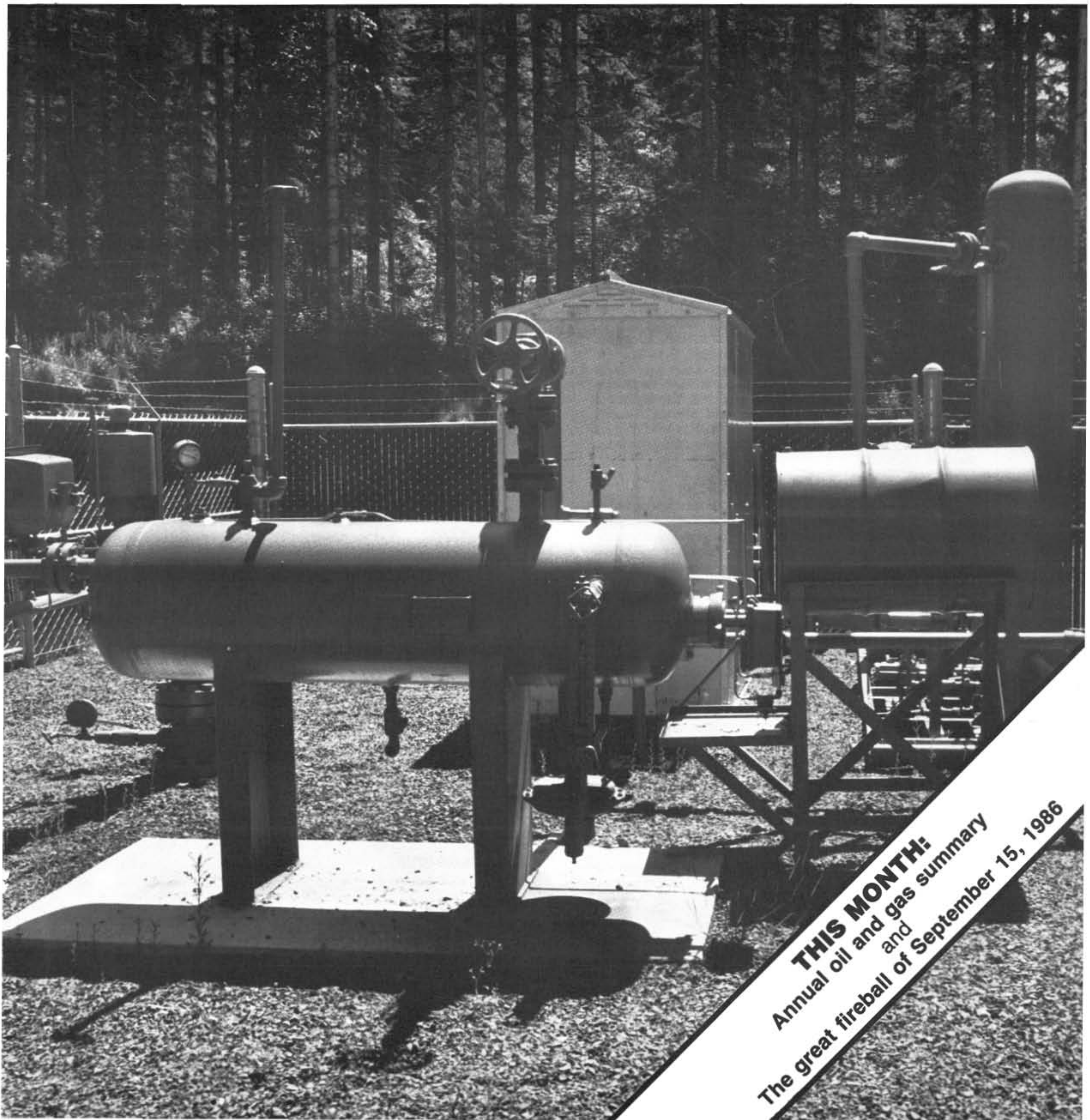

THIS MONTH:
Annual oil and gas summary
and
The great fireball of September 15, 1986

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Production facilities at the ARCO Columbia County 23-22 well site. During 1986, this well produced over one billion cubic feet of gas from a depth of 1,329 feet. Article beginning on next page summarizes oil and gas exploration and development activity in Oregon during 1986.

OIL AND GAS NEWS

Mist gas storage project

Oregon Natural Gas Development has completed drilling wells for the gas storage project in which gas will be injected and stored in the depleted Flora and Bruer Pools. Three observation-monitor wells were completed in January, bringing to six the total number of observation-monitor wells at the project. These are the OM 12c-3 in NW¼ sec. 3, T. 6 N., R. 5 W., the OM 14a-3 in SW¼ sec. 3, T. 6 N., R. 5 W., and the OM 32b-11 in NE¼ sec. 11, T. 6 N., R. 5 W. These had total depths of 3,156 ft, 3,200 ft, and 3,205 ft, respectively.

Observation-monitor wells are used to monitor pressures and gas levels in the storage reservoirs. The injection well IW 34d-3 in SE¼ sec. 3, T. 6 N., R. 5 W., was completed at a total depth of 2,272 ft. There are two injection wells at the project, and they are used to inject gas into and withdraw gas from the storage reservoirs. Injection was scheduled to begin during February.

Recent permits

Permit no.	Operator, well API number	Location	Status, proposed total depth (ft)
378	ARCO Longv. Fibre 23-33-65 36-009-00215	SW¼ sec. 33 T. 6 N., R. 5 W. Columbia County	Application; 2,400.
379	ARCO Col. Co. 11-7-65 36-009-00216	NW¼ sec. 7 T. 6 N., R 5 W. Columbia County	Application; 3,800.
380	ARCO Col. Co. 11-34-65 36-009-00217	NW¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Application; 2,400.
381	ARCO Col. Co. 23-18-65 36-009-00218	SW¼ sec. 18 T. 6 N., R. 5 W. Columbia County	Application; 3,600.
382	ARCO Col. Co. 32-26-65 36-009-00219	NE¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Application; 2,200.
383	ARCO Col. Co. 32-9-65 36-009-00220	NE¼ sec. 9 T. 6 N., R. 5 W. Columbia County	Application; 2,900.
384	ARCO Col. Co. 24-26-65 36-009-00221	SW¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Application; 2,000.
385	ARCO Col. Co. 22-27-65 36-009-00222	NW¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Application; 2,300.
386	ARCO Col. Co. 41-34-65 36-009-00223	NE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Application; 2,400.
387	ARCO Col. Co. 31-27-65 36-009-00224	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Application; 2,300. □

Oil and gas exploration and development in Oregon, 1986

by Dan E. Wermiel, Petroleum Geologist, and Dennis Olmstead, Petroleum Engineer, Oregon Department of Geology and Mineral Industries

ABSTRACT

Oil and gas leasing in Oregon during 1986 decreased greatly from the previous year. Leases on 2.8 million acres of land were withdrawn or terminated during 1986. Columbia County remains the region of the State with the greatest concentration of leases.

The number of applications for permits to drill was down from 1985, as was drilling activity. Eleven exploratory wells, three gas storage wells, and two redrills were drilled during the year. Of these, all but one were in the Mist Gas Field in Columbia County. Four operators were active in the State, producing two new completions, both drilled by ARCO Oil and Gas Company.

Production in 1986 totaled 4.6 billion cubic feet of gas, for a value of approximately $9.2 million.

Oregon Natural Gas Development Corporation, a subsidiary of Northwest Natural Gas Company, began drilling at the natural gas storage project at Mist Gas Field, where the depleted Bruer and Flora Pools will be used for gas storage purposes.

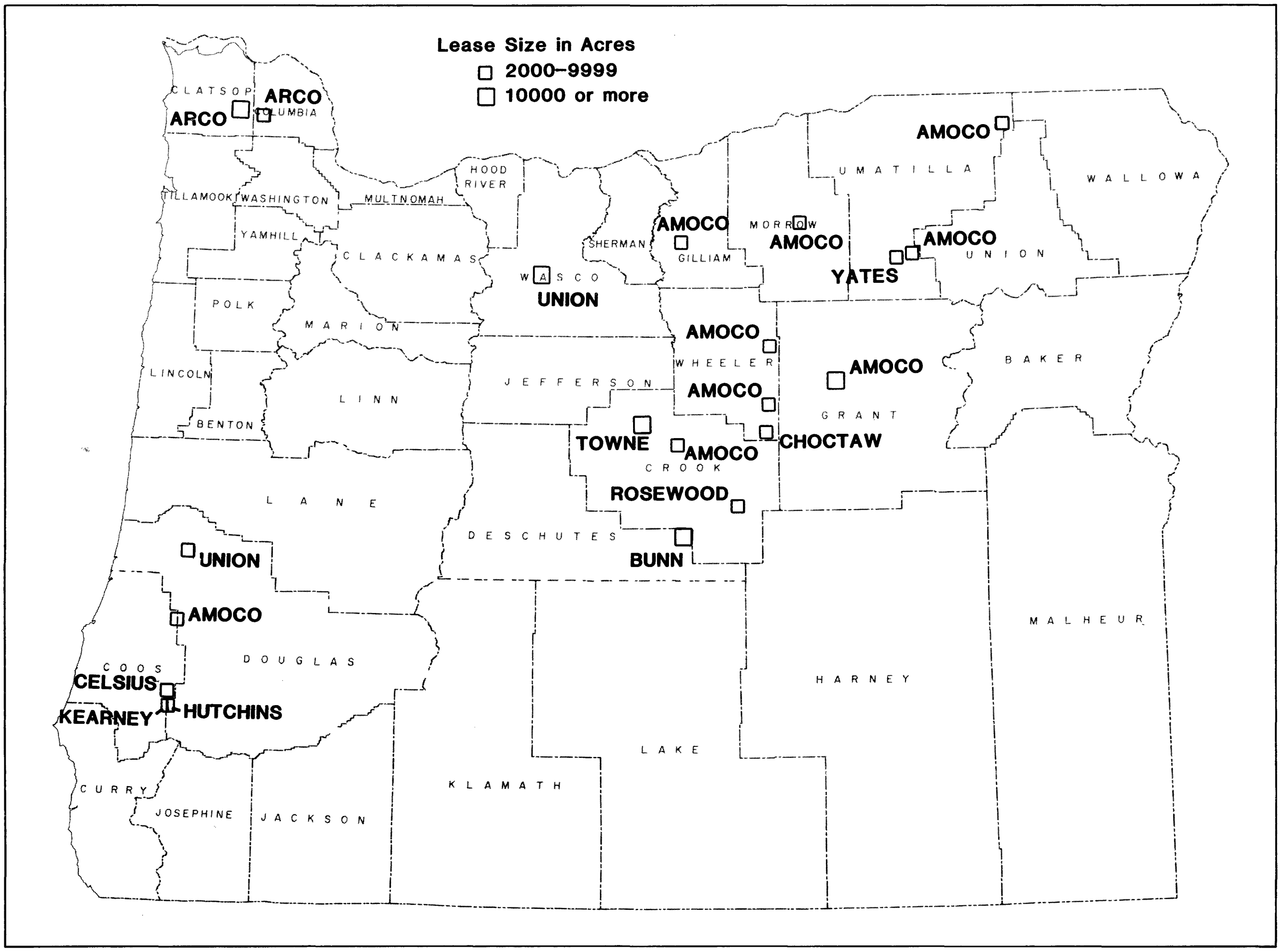
The Division of State Lands passed rules relating to permitting for offshore geological and geophysical surveys. The Oregon Department of Geology and Mineral Industries held public hearings on requests for extension of confidentiality periods on two wells.

LEASING ACTIVITY

Oil and gas leasing in Oregon followed the national trend in that more leases were relinquished and terminated than new leases were issued. On Federal lands in the State, 21 new applications were filed for a total of 101,983 acres. Some of these were for parcels for which application had been made in 1985. The most active counties were Wheeler (45,627 acres), Crook (41,179 acres), and Umatilla (31,276 acres). During the year, leases on 949 tracts expired, were terminated, or were relinquished, a total of 2.6 million acres. At year's end, Oregon had 842 Federal tracts under lease, comprising 1,557,626 acres. Rental income for the year was $1.6 million.

No lease sales of State lands were held during the year, but 34,248 acres of existing leases expired or were dropped. This left 266,832 acres of State land under lease at year's end. Counties with the most State land held under lease last year were Malheur, Harney, and Clatsop. Early in 1987, however, Malheur and Harney Counties lost much of their leased acreage.

Columbia County was the only county to hold a lease sale during the year. A total of 292 tracts was offered, and 76 received bids. The acreage involved was 19,070, earning $134,000 in bonus bids for the County. The high bid was $70 per acre by ARCO Oil and



Major oil and gas leasing in Oregon, 1986. Map shows acreage applied for, issued, and assigned. Withdrawals and terminations are not shown. Data courtesy Greater Columbia LANDATA.

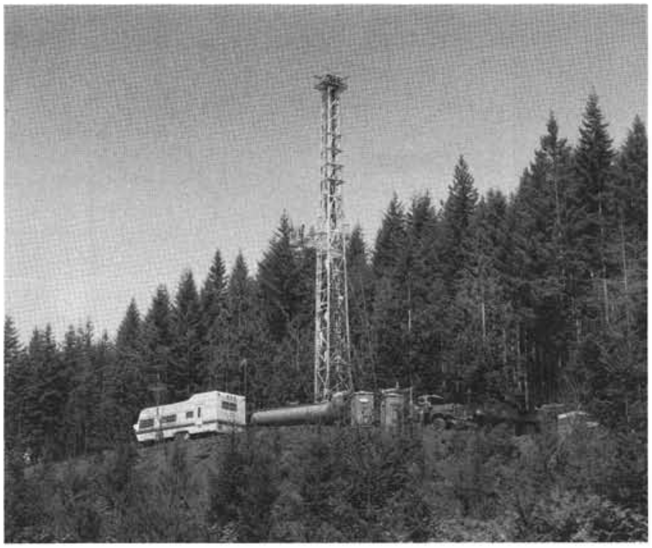
Table 1. *Oil and gas permits and drilling activity in Oregon, 1986*

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD=total depth PTD=proposed TD RD=redrill
299	Tenneco Oil Co. Columbia County 24-28 36-009-00145	SW¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,928.
318	ARCO Oil and Gas Co. Columbia County 14-23 36-009-00161	SW¼ sec. 23 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,180.
325	ARCO Oil and Gas Co. Columbia County 41-6 36-009-00167	NE¼ sec. 6 T. 5 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,750.
341	ARCO Oil and Gas Co. Longview Fibre 41-35 36-009-00182	NE¼ sec. 35 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 1,585.
345	ARCO Oil and Gas Co. Longview Fibre 13-6 36-009-00186	SW¼ sec. 6 T. 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 1,473.
346	ARCO Oil and Gas Co. CFI* 23-9 36-009-00187	SW¼ sec. 9 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 2,904.
347	ARCO Oil and Gas Co. CFI* 41-9 & Redrill 1 36-009-00188 36-009-00188-01	NE¼ sec. 9 T. 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 2,500, RD: 2,501
348	ARCO Oil and Gas Co. CFI* 33-9 36-009-00189	SE¼ sec. 9 T 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 3,242.
352	ARCO Oil and Gas Co. Columbia County 44-27 36-009-00191	SE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,360.
353	ARCO Oil and Gas Co. Longview Fibre 43-4 36-009-00192	NE¼ sec. 4 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
354	ARCO Oil and Gas Co. Columbia County 44-6 36-009-00193	SE¼ sec. 6 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
355	ARCO Oil and Gas Co. Columbia County 31-7 36-009-00194	NE¼ sec. 7 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
356	ARCO Oil and Gas Co. Columbia County 13-21 36-009-00195	SW¼ sec. 21 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
358	Damon Petroleum Corp. Stauffer Farms 35-1 36-047-00020	NW¼ sec. 35 T. 4 S., R. 1 W. Marion County	Evaluating; TD: 2,752.
359	ARCO Oil and Gas Co. CFI* 21-22 36-009-00196	NW¼ sec. 22 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 3,315.
363	Oregon Nat. Gas Dev. OM 44d-3 36-009-00200	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,400.
364	Oregon Nat. Gas Dev. OM 12c-3 36-009-00201	NW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,400.
365	Oregon Nat. Gas Dev. OM 12d-10 36-009-00202	NW¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,805.
366	Oregon Nat. Gas Dev. OM 41a-10 36-009-00203	NE¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 3,067.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1986* —continued

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD=total depth PTD=proposed TD RD=redrill
367	Oregon Nat. Gas Dev. OM 14a-3 36-009-00204	SW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,400.
368	ARCO Oil and Gas Co. CFI* 41-4 & Redrill 1 36-009-00205 36-009-00205-01	NE¼ sec. 4 T. 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 2,584, RD: 1,935.
369	ARCO Oil and Gas Co. CFI* 31-22 36-009-00206	NE¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,400.
370	ARCO Oil and Gas Co. CFI* 12-5 36-009-00207	NW¼ sec. 5 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 4,850.
371	ARCO Oil and Gas Co. CFI* 12-12 36-009-00208	NW¼ sec. 12 T. 5 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,862.
372	Oregon Nat. Gas Dev. OM 32b-11 36-009-00209	NE¼ sec. 11 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
373	Oregon Nat. Gas Dev. IW 34d-3 36-009-00210	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,800.
374	Oregon Nat. Gas Dev. OM 44a-3 36-009-00211	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 3,655.
375	ARCO Oil and Gas Co. Columbia County 31-8 36-009-00212	NE¼ sec. 8 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 4,054.
376	ARCO Oil and Gas Co. Columbia County 42-8-54 36-009-00213	NE¼ sec. 8 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 2,750.
377	ARCO Oil and Gas Co. Longview Fibre 11-31 36-009-00214	NW¼ sec. 31 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD: 2,300.

*CFI = Cavenham Forest Industries



Drilling operations at ARCO Columbia County 14-23, which was successfully completed as a gas producer in 1986.

Table 2. *Canceled and denied permits, 1986*

Permit no.	Operator, well, API number	Location	Issue date	Cancellation date	Reason
255	ARCO Oil and Gas Co. Columbia County 13-34A 36-009-00123	SW¼ sec. 34 T. 7 N., R. 5 W. Columbia County	1-13-84	4-7-86	Permit canceled; expired.
260	AMOCO Production Co. Weyerhaeuser 1-26 36-019-00024	SW¼ sec. 26 T. 25 S., R. 9 W. Douglas County	5-25-84	5-25-86	Permit canceled; expired.
261	AMOCO Production Co. Weyerhaeuser 1-34 36-019-00025	NW¼ sec. 34 T. 25 S., R. 9 W. Douglas County	5-25-84	5-25-86	Permit canceled; expired
267	AMOCO Production Co. Weyerhaeuser 1-6 36-019-00026	SW¼ sec. 6 T. 25 S., R. 8 W. Douglas County	--	--	Permit denied; failure to post drilling bond.
281	Leavitts Exploration Jackson 1 36-039-00006	NW¼ sec. 14 T. 19 S., R. 4 W. Lane County	1-10-85	1-10-86	Permit canceled; expired.
282	Leavitts Exploration Jackson 2 36-039-00007	SW¼ sec. 11 T. 19 S., R. 4 W. Lane County	1-10-85	1-10-86	Permit canceled; expired.
286	Ty Settles Cindy 2 36-039-00009	SW¼ sec. 23 T. 16 S., R. 5 W. Lane County	--	--	Permit denied; failure to post drilling bond.
291	Hutchins and Marrs Discovery 1 36-019-00031	NW¼ sec. 17 T. 30 S., R. 9 W. Douglas County	4-12-85	4-12-86	Permit canceled; expired.
294	Oregon Nat. Gas Dev. Tesch 44-21 36-047-00019	SE¼ sec. 21 T. 5 S., R. 2 W. Marion County	5-13-85	5-13-86	Permit canceled; expired.
303	ARCO Oil and Gas Co. Columbia County 11-31 36-009-00149	NW¼ sec. 31 T. 6 N., R. 3 W. Columbia County	5-28-85	6-13-86	Permit canceled; expired.
304	ARCO Oil and Gas Co. Columbia County 33-28 36-009-00150	SE¼ sec. 28 T. 5 N., R. 5 W. Columbia County	5-28-85	1-3-86	Permit canceled; lease expiration.
305	ARCO Oil and Gas Co. Columbia County 41-14 36-009-00151	NE¼ sec. 14 T. 4 N., R. 3 W. Columbia County	5-28-85	1-3-86	Permit canceled; lease expiration.
308	EXXON Corp. Columbia County 1 36-009-00154	NE¼ sec. 29 T. 5 N., R. 3 W. Columbia County	7-17-85	7-17-86	Permit canceled; expired
311	EXXON Corp. Crown Zellerbach 1 39-009-00157	NE¼ sec. 28 T. 5 N., R. 3 W. Columbia County	7-17-85	7-17-86	Permit canceled; expired.
312	EXXON Corp. GPE Federal 3 36-009-00158	SW¼ sec. 35 T. 5 N., R. 3 W. Columbia County	7-17-85	7-17-86	Permit canceled; expired.
313	ARCO Oil and Gas Co. Columbia County 22-19 36-009-00159	NW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	6-20-85	6-20-86	Permit canceled; expired.
315	Leavitt Exploration Falk 3 36-039-00010	NE¼ sec. 13 T. 16 S., R. 5 W. Lane County	--	--	Permit denied; failure to post drilling bond.

Table 2. *Canceled and denied permits, 1986* — continued

Permit no.	Opertor, well, API number	Location	Issue date	Cancellation date	Reason
316	Leavitt Exploration Jessie 1 36-039-00011	SW¼ sec. 13 T. 16 S., R. 5 W. Lane County	--	--	Permit denied; failure to post drilling bond.
319	ARCO Oil and Gas Co. Columbia County 14-18 36-009-00162	SW¼ sec. 18 T. 4 N., R. 3 W. Columbia County	--	--	Permit denied; irregular location waiver denied by County.
321	Tenneco Oil Co. Columbia County 12-15 36-009-00164	NW¼ sec. 15 T. 5 N., R. 5 W. Columbia County	9-3-85	1-6-86	Permit canceled; lease expiration.
322	Tenneco Oil Co. Columbia County 24-10 36-009-00165	SW¼ sec. 10 T. 5 N., R. 5 W. Columbia County	8-7-85	1-6-86	Permit canceled; lease expiration
326	ARCO Oil and Gas Co. Columbia County 33-6 36-009-00168	SE¼ sec. 6 T. 5 N., R. 5 W. Columbia County	8-20-85	8-20-86	Permit canceled; expired.
328	EXXON Corp. Columbia County "B" 1 36-009-00169	SW¼ sec. 2 T. 4 N., R. 3 W. Columbia County	9-3-85	9-3-86	Permit canceled; expired.
329	EXXON Corp. Columbia County "C" 1 36-009-00170	NW¼ sec. 14 T. 4 N., R. 3 W. Columbia County	9-3-85	9-3-86	Permit canceled; expired.
330	ARCO Oil and Gas Co. Columbia County 33-35 36-009-00171	SE¼ sec. 35 T. 7 N., R. 5 W. Columbia County	9-25-85	9-25-86	Permit canceled; expired.
331	ARCO Oil and Gas Co. Columbia County 43-32 36-009-00172	SE¼ sec. 32 T. 6 N., R. 5 W. Columbia County	9-25-85	9-25-86	Permit canceled; expired.
332	ARCO Oil and Gas Co. Columbia County 11-34 36-009-00173	NW¼ sec. 34 T. 6 N., R. 5 W. Columbia County	9-25-85	1-3-86	Permit canceled; lease expiration.
334	ARCO Oil and Gas Co. Columbia County 13-3 36-009-00172	SW¼ sec. 3 T. 5 N., R. 5 W. Columbia County	9-25-85	9-25-86	Permit canceled; expired.
335	ARCO Oil and Gas Co. Columbia County 41-24 36-009-00176	NE¼ sec. 24 T. 4 N., R. 4 W. Columbia County	9-30-85	1-3-86	Permit canceled; lease expiration.
336	ARCO Oil and Gas Co. Columbia County 22-7 36-009-00177	NW¼ sec. 7 T. 6 N., R. 5 W. Columbia County	9-30-85	9-30-86	Permit canceled; expired.
340	ARCO Oil and Gas Co. Columbia County 14-30 36-009-00181	SW¼ sec. 30 T. 6 N., R. 3 W. Columbia County	10-2-85	10-2-86	Permit canceled; expired.
342	ARCO Oil and Gas Co. Columbia County 31-27 36-009-00183	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	12-2-85	12-2-86	Permit canceled; expired.
343	ARCO Oil and Gas Co. Longview Fibre 34-25 36-009-00184	SE¼ sec. 25 T. 6 N., R. 5 W. Columbia County	12-2-85	12-2-86	Permit canceled; expired.
349	Hutchins & Marrs Great Discovery 3 36-019-00033	SW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	--	--	Permit denied; failure to post drilling bond.

Table 2. *Canceled and denied permits, 1986* — continued

Permit no.	Opertor, well, API number	Location	Issue date	Cancellation date	Reason
350	Hutchins & Marrs Discovery 3 36-019-00034	NE¼ sec. 17 T. 30 S., R. 9 W. Douglas County	--	--	Permit denied; failure to post drilling bond.
351	ARCO Oil and Gas Co. Longview Fibre 14-25 36-009-00190	SW¼ sec. 25 T. 6 N., R. 5 W. Columbia County	--	--	Permit denied; spacing unit exception not granted.
357	Hutchins & Marrs GP 2 36-011-00023	NE¼ sec. 14 T. 30 S., R. 10 W. Coos County	--	--	Permit denied; failure to post drilling bond.
360	ARCO Oil and Gas Co. Columbia County 42-8 36-009-00197	NE¼ sec. 8 T. 5 N., R. 5 W. Columbia County	5-20-86	9-9-86	Permit canceled; lease expiration.
361	ARCO Oil and Gas Co. Columbia County 12-6 36-009-00198	NW¼ sec. 6 T. 5 N., R. 5 W. Columbia County	5-20-86	11-3-86	Permit canceled; lease expiration.
362	ARCO Oil and Gas Co. Columbia County 21-11 36-009-00199	NW¼ sec. 11 T. 5 N., R. 3 W. Columbia County	6-11-86	11-3-86	Permit canceled; lease expiration.

Wellhead at ARCO Columbia County 14-23.

propose legislation in 1987. Details can be obtained from DOGAMI. The Department contributed input to the rulemaking by the Division of State Lands regarding permitting for offshore geological and geophysical activity and surveys to be conducted in State waters.

DOGAMI converted a deserted well in Wheeler County, Steel Energy Keys No. 1, to a water well, using drilling bond money posted for the well. ARCO Oil and Gas Company requested a one-year extension of the standard two-year confidentiality period for well records on Werner 34-21 in Marion County and Paul 34-32 Redrills 1 and 2 in Columbia County. DOGAMI held public hearings on the matter, and the extension of confidentiality was denied on the Werner 34-21 but granted on the Paul 34-32 redrills, a decision which was on appeal at year's end. The Mist Gas Field map has been updated through October 1986 and is available from DOGAMI, as are publications in the Oil and Gas Investigation Series and others relating to the Mist Gas Field.

Columbia County, in which the Mist Gas Field is located, has adopted a new lease form that affects the acreage offered for sale by the County in the future. The annual rental is $10 per acre with a term of 10 years. There is also a five-year drilling commitment, with a $5 annual penalty per acre after the five-year period. Information can be obtained from Columbia County, St. Helens, Oregon, phone (503) 397-4322. □

Bureau of Mines names new Spokane chief

The U.S. Bureau of Mines recently appointed Richard B. Grabowski as Chief of its Western Field Operations Center in Spokane. Grabowski spent most of his career in the western United States managing mineral exploration and development for several industrial firms. His most recent position was as chief geologist for Cabot Mineral Resources, a multinational firm based in New York.

In his new position, Grabowski will be responsible for a variety of programs that assess the nation's mineral resource potential and the adequacy of its mineral supply. The Center's work includes examination of individual mines and mineral deposits, evaluation of the mineral potential of public lands, and engineering and economic studies of mineral commodities and the industries that produce them. —*BLM News*

The great fireball of September 15, 1986

by Richard N. Pugh, Science Teacher, Cleveland High School, Portland, Oregon

A great bolide (large fireball) occurred over the Cascade Mountains of Oregon on September 15, 1986, at 9:51 p.m., Pacific Daylight Time. It moved from the north-northeast to the south-southwest, entering the atmosphere north of Hood River and disappearing near the village of Vida, east of Eugene. It is the largest fireball reported over Oregon since the December 3, 1981, fireball over Silverton (Pugh, 1982).

This report is based on the observations of 37 people. The fireball was seen as far north as Timberline Lodge on the south side of Mount Hood, as far east as Baker in eastern Oregon, as far west as Coos Bay on the coast, and as far south as Central Point in Jackson County. Estimates of the size of the bolide ranged from one to ten times the diameter of the full moon. In almost all cases, the brightness was reported to be greater than that of a full moon. Two observers reported that the object was too bright to look at directly. In almost all cases, the fireball lit up the land, casting shadows.

The color of the fireball varied from white to red, yellow-white being the most commonly reported color. However, there were many reports of blue or green edges around the yellow-white center. Most observers saw a tail coming off of the fireball. The length of the tail ranged from 5° to 60°, and its color was most commonly reported to be yellow-orange. There were numerous reports of sparks, streamers, smoke, and vapor trails associated with the fireball. As many as 12 large fragments were reported.

Sonic booms were reported near Tygh Valley, Madras, Prineville, Albany, and McKenzie Bridge. There were also reports of anomalous sounds associated with the fireball. The anomalous sounds are not the same as sonic booms. They are sounds heard the same time the fireball is seen, although the fireball may be many miles away from the observer. As sound travels slower than the speed of light, the occurrence of these sounds with the visual observations is not yet understood.

One observer saw the fireball split into two pieces east of Mulino, Oregon. One piece appeared to be spinning, the other not. The fireball again broke up or exploded just before termination.

The presence of sonic booms during this event indicated that meteorites were produced from this fireball. Plotting of fireball sightings indicated that the area of impact was probably east of Eugene/Springfield, near the town of Vida on the McKenzie River. As this is a rugged and heavily timbered part of the western Cascades, unless one of the meteorites struck a building, it is unlikely that specimens will be recovered (Pugh, 1986).

At present, Oregon has produced five meteorites. Four were finds, that is, they were found after having been on the ground for hundreds of years. The only meteorite that was actually recovered right after falling was the Salem stony meteorite, which fell May 13, 1981 (Pugh, 1983). Even though several meteorites undoubtedly fall every year in Oregon, their recovery is difficult due to the geography, geology, frequently cloudy weather, and population distribution.

Picture painted by artist Nancy Jo Farry, who saw the September 15 fireball from Coos Bay, Oregon. Photo by Memo Jasso.

It is hoped that readers will be on the lookout for these space rocks. Anyone who thinks that he might have a meteorite should contact the author at Cleveland High School, 3400 S.E. 26th Ave., Portland, OR 97202, phone (503) 280-5120.

REFERENCES CITED

Pugh, R.N., 1982, December 3, 1981, fireball: Oregon Geology, v. 44, no. 6, p. 69-70.

——1983, The Salem meteorite: Oregon Geology, v. 45, no. 6, p. 63-64.

——1986, Report to SEAN: Scientific Event Alert Network Bulletin, v. 11, no. 9, p. 21. □

New list of field trip guides available

The Geoscience Information Society (GIS) has published the fourth edition of its *Union List of Geologic Field Trip Guidebooks of North America*. The 200-page publication is available from Customer Services, American Geological Institute (AGI), 4220 King Street, Alexandria, VA 22302, for the price of $47.50.

The new edition lists guidebooks for field trips held from 1891 through the end of 1979, including the holdings of 134 libraries in Canada and the United States with strong geoscience collections. Useful as both a bibliography and a finding tool, it helps the user to determine quickly which libraries own a copy of any guidebook cited and what the lending policies of those libraries are.

It is often difficult to obtain guidebooks for the field trips held at geology meetings every year. Few are available for purchase after the field trips have taken place. That is why GIS has over the years given high priority to production of the Union List. This fourth edition has listings of 566 guidebook series, compared to 354 in the previous edition, and a greatly expanded geographic index. The publication is a cooperative effort of the 134 libraries, the GIS Guidebooks Committee, and the AGI library staff. The compilation and editing were directed by Beatrice Lukens of the AGI, who chaired the GIS Guidebooks Committee. □

Glimpses of DOGAMI history — the beginnings

Fifty years ago, on March 1, 1937, Chapter 179 of the Oregon Laws was signed by the Governor and filed in the office of the Secretary of State. It began: "There hereby is created and established a State Department of Geology and Mineral Industries." That start of the Department is reflected in the following glimpses of DOGAMI history.

From The Way it Was, *a brief history of the Department by Ralph S. Mason, former State Geologist. The paper will soon be released by DOGAMI.*

"In the spring of 1937, the Legislature created the present Department of Geology and Mineral Industries and for the first biennium appropriated $60,000 for the Department, along with an additional $40,000 that was earmarked for grubstakes for prospectors and for administering the "Grubstake Act" during the biennium.e first meeting of the Department's Governing Board, which had been appointed by the Governor, took place on April 7, 1937, about a month after the Department had been created. The Board members had been chosen partly because of their interest in mining and geology and partly by reasons of regional representation. They were Senator W.H. Strayer from Baker County, who had long campaigned for the formation of a Department; Albert Burch from Jackson County, who was a consulting mining engineer; and E.B. MacNaughton from Multnomah County, who was a banker and civic leader. Senator Strayer was appointed Chairman. . .

"By June 8, 1937 . . . the Board had selected Earl K. Nixon to be the first Director of the Department. Earl Nixon was a mining engineer with wide experience in many parts of the world. At the time of his appointment, Nixon was operating a placer mine in Josephine County . . . From his first moment in the driver's seat, the new Director, with the full cooperation of the Board (which met ten times during the first year), launched a blizzard of programs and projects. To accomplish as many tasks as possible in the shortest time, Nixon established a 44-hour work week for the Department and kept the office open during noon hours to accommodate both local and out-of-town patrons and also to receive phone calls originating in other time zones. For many years, thanks to flexible work schedules, the Portland office was open from shortly after 7:00 a.m. until 5:30 p.m. Professional staffers working on rush projects in the evening reported calls coming in as late as 9:00 p.m. and later.

"The title of State Geologist, which had been originally conferred on Dr. [Thomas] Condon [in 1872], was not given to the new Director of the Department. It was not until 1963 that the position of State Geologist was restored."

From the first issue of the Department's Press Bulletins *(which in 1939 were changed into the monthly magazine* The Ore. Bin*), Press Bulletin No. 1, November 1, 1937.*

"*Mining Bureau Created.* The last session of the State Legislature authorized a State Department of Geology and Mineral Industries which is to stimulate mining activity in the State and to locate markets where Oregon products may be sold . . .

"The head office is located in Portland, with Earl K. Nixon as Director of the Department, Mr. A.M. Swartley as Consulting Mining Engineer, and Mr. Ray C. Treasher as Geologist. Offices are maintained in the Lewis Building at the corner of Southwest Fourth and Oak. Mr. Donald K. Mackay is Mining Geologist at Baker, where the State Assay Laboratory is conducted by Mr. Leslie L. Motz. Mr. J.E. Morrison, Mining Geologist, is at Grants Pass, where the State Assay Laboratory is conducted by Mr. Albert A. Lewis." □

Oregon earthquakes recorded on new map

A new map published by the Oregon Department of Geology and Mineral Industries (DOGAMI) depicts the locations and magnitudes of all earthquakes that are known to have occurred in Oregon and southern Washington between 1841 and 1986. It is map GMS-49 in DOGAMI's Geological Map Series.

The black-and-white *Map of Oregon Seismicity, 1841-1986*, produced by R.S. Jacobson during his tenure at the College of Oceanography, Oregon State University, measures approximately 2 by 3 ft and depicts the earthquake epicenters on a background showing the state, its counties, and selected cities. It includes all earthquakes recorded in the unpublished Seismic Catalog of Oregon State University. A total of 1,286 earthquake events are recorded, of which approximately 440 were associated with the eruption of Mount St. Helens in 1980. Approximately 250 of the listed events occurred before 1962, when modern recording instrumentation became available. The map also contains a brief discussion by the author, a table listing the seven largest earthquakes in Oregon, and a bibliography with suggestions for further reading.

The author advises caution in using this map alone to define earthquake hazards within Oregon. The historical record is not sufficiently extensive and not exact enough for that. Also, areas outside the State, such as Puget Sound, Mount St. Helens, or the Blanco Fracture Zone off the coast, could create earthquake hazards within Oregon. He finally describes the different attempts by scientists to explain the phenomenon that Oregon has had relatively few and only moderate earthquakes in the past and to solve the question whether one may expect only moderate earthquake activity or greater earthquake activity in the future.

The new map, GMS-49, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, Portland, OR 97201. The purchase price is $3. Orders under $50 require prepayment. □

Volcano News devotes one issue to Mount St. Helens

The July 1986 issue of *Volcano News* (no. 24), entitled "Mount St. Helens: The First Six Years," contains short summary articles on Mount St. Helens activity, prediction of eruptions, rockslide/debris avalanches, lahars, the blast eruption, erosion of sediments, and petrology and chemical composition of the St. Helens magma by scientists who have studied the volcano for the last six years.

Volcano News, a sort of underground newspaper for volcanologists, appears at varying intervals. The publication is described by its editor Charles Wood in the following way: "Approximately 450 volcanologists and volcano enthusiasts from 30 nations subscribe, including many professional geologists in the U.S. Geological Survey. *VN* tries to be sprightly, interspersing its "serious" articles with reviews of volcano disaster books, volcano art, whimsy, crossword puzzles, and poetry/doggerel. Forthcoming issues include articles on the Aleutians, Central America, remote sensing, and societal effects of volcanic eruptions. Also, I hope to establish the world's first volcano bulletin board on computer in time to have daily reports from the January 1987 symposium in Hawaii on 'How Volcanoes Work'."

Single copies of the eight-page *Volcano News* sell for $2, but Editor Wood assures *Oregon Geology* readers that if anyone wants to subscribe for the next four issues (*VN* 25-28) at $7, he'll include a free copy of the Mount St. Helens issue, if the subscriber asks and also mentions this notice in *Oregon Geology*. Address of *Volcano News* is 320 East Shore Drive, Kemah, TX 77565, phone (713) 538-2135. □

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-4: Oregon gravity maps, onshore and offshore. 1967	$ 3.00		
GMS-5: Geologic map, Powers 15-minute quadrangle, Coos annd Curry Counties. 1971	3.00		
GMS-6: Preliminary report on geology of part of Snake River canyon. 1974	6.50		
GMS-8: Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-9: Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-10: Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00		
GMS-12: Geologic map of the Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	3.00		
GMS-13: Geologic map, Huntington and part of Olds Ferry 15-min. quadrangles, Baker and Malheur Counties. 1979	3.00		
GMS-14: Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00		
GMS-15: Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00		
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GMS-24: Geologic map, Grand Ronde 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-25: Geology and gold deposits map, Granite 7½-minute quadrangle, Grant County. 1982	5.00		
GMS-26: Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00		
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GMS-29: Geology and gold deposits map, NE¼ Bates 15-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-30: Geologic map, SE¼ Pearsoll Peak 15-minute quadrangle, Curry/Josephine Counties. 1984	6.00		
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GMS-35: Geology and gold deposits map, SW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-36: Mineral resources map of Oregon. 1984	8.00		
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GMS-38: Geologic map, NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	6.00		
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OTHER MAPS

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Oregon Landsat mosaic map (published by ERSAL, OSU). 1983 .....$8.00 over the counter, $11.00	mailed		
Geothermal resources of Oregon (map published by NOAA). 1982	3.00		
Geological highway map, Pacific Northwest region, Oregon/Washington/part of Idaho (published by AAPG). 1973	5.00		
Mist Gas Field Map, showing well locations, revised 10/86 (DOGAMI Open-File Report O-84-2, ozalid print)	5.00		
Northwest Oregon, Correlation Section 24. Bruer & others, 1984 (published by AAPG)	5.00		

BULLETINS

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Mining claims (State laws governing quartz and placer claims)	1.00		
Back issues of *Ore Bin*	50¢ over the counter; $1.00 mailed		
Back issues of *Oregon Geology*	75¢ over the counter; $1.00 mailed		

Separate price lists for open-file reports, geothermal energy studies, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request.

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VOLUME 49, NUMBER 4 APRIL 1987

THIS MONTH:

Mineral industry in Oregon, 1986

and

Trace fossil *Gyrolithes* from the Astoria Formation

OREGON GEOLOGY
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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

One of several exploration holes drilled by Kennecott Exploration on the old Almeda Mine property in Josephine County. Kennecott is evaluating a massive sulfide occurrence containing gold, silver, copper, lead, and zinc, from which there was production between 1911 and 1916. See related article beginning on next page.

OIL AND GAS NEWS

ARCO applications permitted

Permits to drill have been issued on nine of the ten applications received from ARCO during February. These are all located in T. 6 N., R. 5 W., Columbia County, and are the Columbia County 11-7-65, Columbia County 11-34-65, Columbia County 23-18-65, Columbia County 32-26-65, Columbia County 32-9-65, Columbia County 24-26-65, Columbia County 22-27-65, Columbia County 41-34-65, and Columbia County 31-27-65. The Longview Fibre 23-33-65 has not yet been permitted at this time.

In addition, a one-year extension was granted on two ARCO permits. The Cavenham Forest Industrics 31-22, sec. 22, T. 6 N., R. 5 W., was extended to July 18, 1988, and the Columbia County 13-21, sec. 21, T. 6 N., R. 5 W, was extended to March 28, 1988.

Gas storage project started

Oregon Natural Gas Development has started preliminary injection tests at the two pools now tapped for gas storage. The pools will be repressured to 75 percent of their original pressures in 1987, or about 800 psi for the Flora Pool and 725 psi for the Bruer Pool. Gas for the repressuring is 60 percent Mist gas from other pools and 40 percent pipeline gas. A tracer is used in the injected gas to detect any leakage to other pools. The first withdrawal will occur in the fall of this year.

Mist Gas Field map updated

The Mist Gas Field map showing well locations, status, and depths has been updated as of March 1, 1987, and is available as Open-File Report O-84-2, *Mist Gas Field Map (revision of 3-87).* Copies of this report may be purchased for $5 from the Portland office of the Oregon Department of Geology and Mineral Industries.

NWPA to hold annual symposium

The Northwest Petroleum Association has scheduled its annual symposium for May 18 and 19, at the Riverhouse Motor Inn in Bend, Oregon. The meeting and field trip will concentrate on the Columbia Basin and Plateau geology and hydrocarbon prospects and will include a talk on current geothermal exploration. The field trip, led by Lewis Kleinhans, will be to the Mitchell area. Topics of discussion at the meeting include leasing activity, tectonic overview, structural evolution, Cretaceous stratigraphy, geophysical techniques, and hydrocarbon prospects. For further information contact Phil Brogan, (503) 382-0560, or the NWPA, P.0. Box 6679, Portland, OR 97228. □

Geologic maps trace ancient coast in Clackamas and Marion Counties

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two geologic maps to complete a block of five 7½-minute quadrangle maps showing ancient sea-shore environments in the foothills of the central Western Cascades just east of Salem.

The new maps are *Geologic Map of the Drake Crossing Quadrangle, Marion County, Oregon*, DOGAMI Geological Map Series GMS-50; and *Geologic Map of the Elk Prairie Quadrangle, Marion and Clackamas Counties, Oregon*, DOGAMI Geological Map Series GMS-51. They were produced by William N. Orr and Paul R. Miller of the University of Oregon. Both maps are at the scale of 1:24,000 and in two colors.

Together with three previously published maps—Wilhoit quadrangle (DOGAMI map GMS-32), Scotts Mills quadrangle

*(Continued on page 48, **Maps**)*

Mineral industry in Oregon, 1986

by Ronald P. Geitgey, Industrial Minerals Geologist, Oregon Department of Geology and Mineral Industries

INTRODUCTION

Preliminary estimates by the U.S. Bureau of Mines place the value of 1986 nonfuel mineral production in Oregon at $131 million, slightly above the 1985 value. Of this total, $92 million was from construction sand, gravel, and crushed stone. Most of the remaining value was contributed by nickel and various industrial minerals.

MINING ACTIVITY

Metals

Placer operations were active in Baker County on Burnt River (5)*, Pine Creek (3), Clarks Creek (2), and Deer Creek (4). Several small-scale seasonal operations continued in Josephine County on Josephine Creek and its tributaries (19), Sucker Creek (20), Althouse Creek (21), Illinois River tributaries (17), and in the Galice area (16) and in Douglas County on Coffee Creek (13).

A small amount of precious metal was produced from the Irish Girl vein of the Greenback Mine (15) in Josephine County. The 900-ft level was rehabilitated, and some drifting was done on the western extension of the Greenback vein.

Hanna Nickel Mining and Smelting Company completed installation of its new wet-screening plant at Nickel Mountain (14) in Douglas County; however, the mill was shut down after only two months of operation. Depressed nickel prices have made the operation uneconomic, and in January 1987 the company announced closure of the mine and mill.

Industrial minerals

Bentonite clay was produced by Central Oregon Bentonite and Oregon Sun Ranch from adjacent properties on Camp Creek (9) in Crook County and by Teague Mineral Products (7) near Adrian in Malheur County. The bentonite is used for drilling muds, pet litter, binder for hay pelletizing, and as sealant for ponds, ditches, and solid-waste disposal sites.

* *All mine numbers in this section refer to "Active Mines" on the location map and in Table 1.*

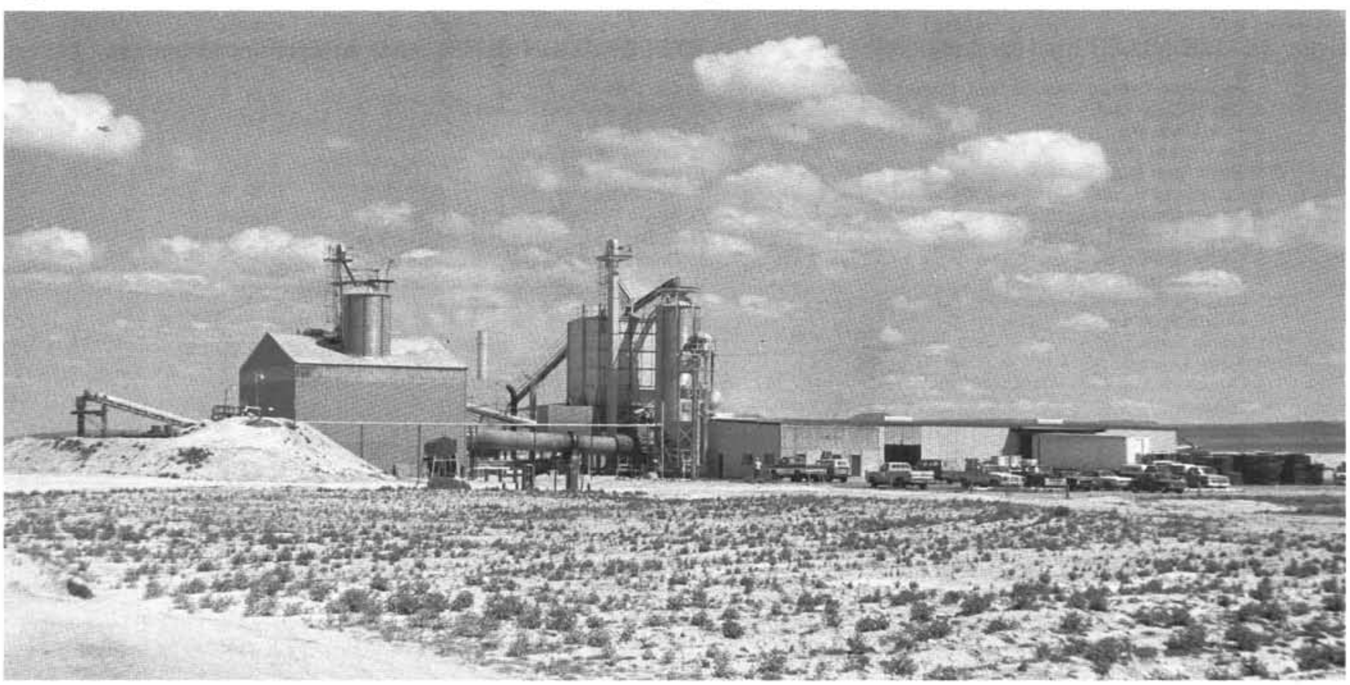
OREGON'S MINERAL PRODUCTION
MILLIONS OF DOLLARS

	ROCK MATERIALS (Sand & Gravel, Stone)	METALS & INDUSTRIAL MINERALS (Cement, Nickel, Pumice, etc.)	NATURAL GAS	TOTAL
1972	54	22	0	76
1973	55	26	0	81
1974	75	29	0	104
1975	73	33	0	106
1976	77	35	0	112
1977	74	35	0	109
1978	84	44	0	128
1979	111	54	+	165
1980	95	65	12	172
1981	85	65	13	163
1982	73	37	10	120
1983	82	41	10	133
1984	75	46	8	129
1985	91	39	10	140
1986	92	39	9	140

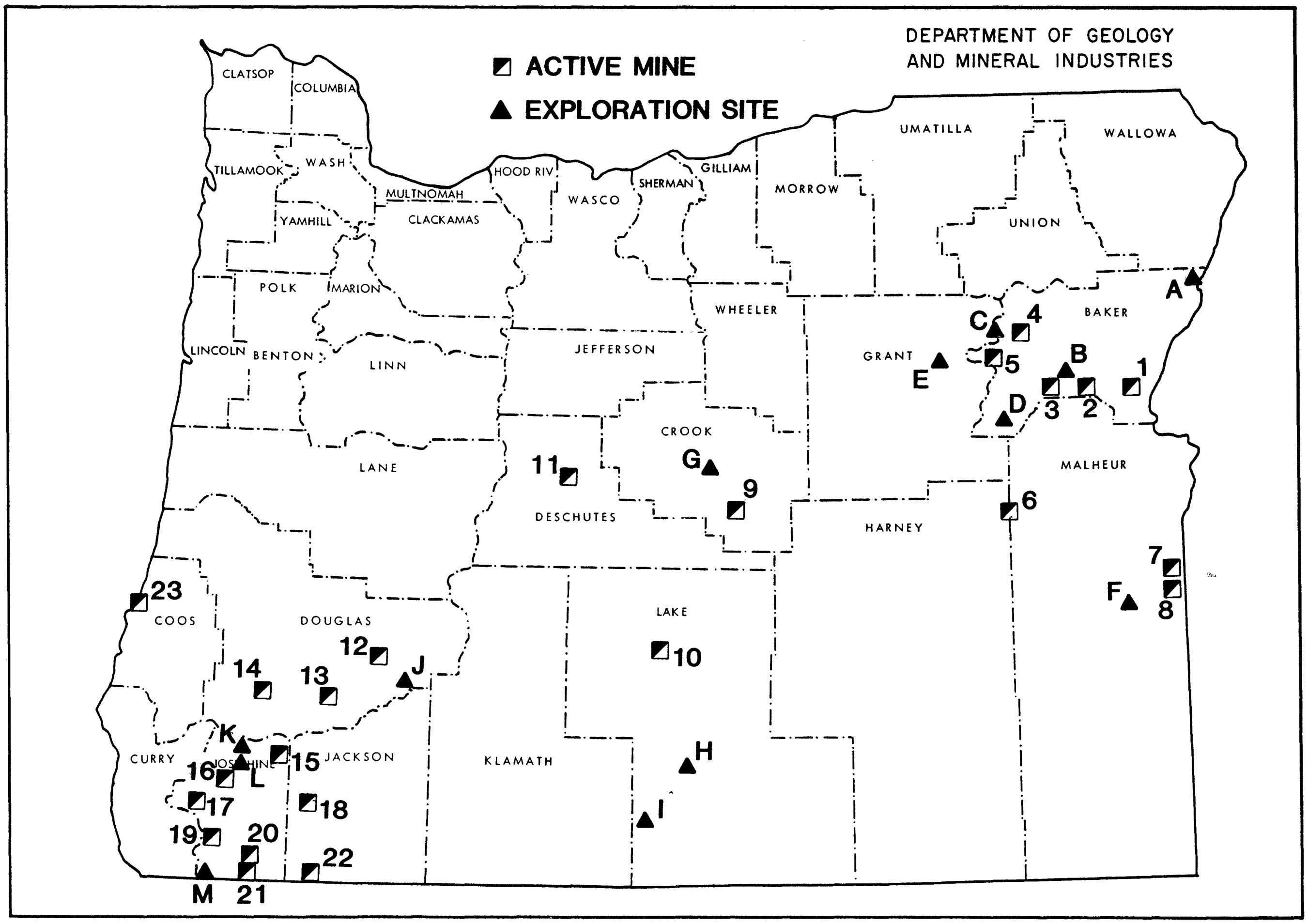
Summary of mineral production in Oregon for the last 15 years. Data for 1986 derived from U.S. Bureau of Mines annual preliminary mineral industry survey and Oregon Department of Geology and Mineral Industries natural gas production statistics.

Teague Mineral Products produced the zeolite mineral clinoptilolite from its mine on Succor Creek (8) in Malheur County. Most of the zeolite was packaged and sold as pet litter, with smaller amounts sold as odor-control products, fungicide carriers, and ammonia absorbent in aquarium systems. Clinoptilolite readily absorbs the element cesium, including its radioactive isotope produced by nuclear fission. A one-ton sample was sent by Teague to Bikini Atoll in the South Pacific to evaluate its absorbent characteristics in preventing cesium uptake by food crops grown in soils contaminated by nuclear testing.

Diatomite production continued by Oil-Dri Production Company in Christmas Valley (10), Lake County. The diatomite is pack-



Oil-Dri Production Company diatomite mill near Christmas Valley in northern Lake County.



EXPLANATION

ACTIVE MINES (half-filled square)

1. Ash Grove Cement West (cement, limestone)
2. Clarks Creek (Au)
3. Pine Creek (Au)
4. Deer Creek (Au)
5. Burnt River (Au)
6. Celatom (diatomite)
7. Teague Mineral Products (bentonite)
8. Teague Mineral Products (zeolite)
9. Camp Creek (bentonite)
10. Oil-Dri (diatomite)
11. Cascade Pumice, Central Oregon Pumice (pumice)
12. Ouartz Mountain Silica (silica)
13. Coffee Creek (Au)
14. Nickel Mountain (Ni)
15. Greenback (Au)
16. Galice area (Au)
17. Illinois River area (Au)
18. Bristol Silica (silica)
19. Josephine Creek (Au)
20. Sucker Creek (Au)
21. Althouse Creek (Au)
22. Steatite of Southern Oregon (soapstone)
23. CooSand (silica sand)

EXPLORATION SITES AND AREAS (solid triangle)

A. Iron Dyke (Au, Ag, Cu)
B. Dooley Mountain (perlite)
C. Ibex (Au, Ag)
D. Grouse Spring (Cu, Mo)
E. Susanville (Au, Ag)
F. Red Butte (Au)
G. Alaska Pacific Oregon, Ltd. (bentonite)
H. Tucker Hill (perlite)
I. Quartz Mountain (Au)
J. Foster Creek area (soil amendment rock)
K. Goff (Au, Ag, Cu, Pb, Zn)
L. Almeda (Au, Cu, Zn)
M. Turner-Albright (Au, Ag, Zn, Cu, Co)

Mining and mineral exploration in Oregon in 1986 (excluding sand and gravel and stone). Active mines are keyed to Table 1; exploration sites are keyed to Table 2.

aged as pet litter for several companies under various brand names.

Eagle-Picher Industries began a diatomite operation with mines in northern Harney and Malheur Counties (6) and a mill near Vale. The diatomite is processed by air classification and flux calcining (heating to produce partial fusion and agglomeration) and sold under the brand name of Celatom. The principal application of the Celatom line of products is as filter aids for filtering water, beverages, syrups, juices, edible oils, fuels, and pharmaceuticals.

Pumice was produced in the Bend area (11), Deschutes County, by Cascade Pumice and Central Oregon Pumice, primarily for a lightweight aggregate in concrete-block manufacturing.

CooSand Corporation continued to produce silica sand from its property on Coos Bay (23), Coos County. The sand is shipped by rail to a plant near Portland. Part of the sand is sold as air-blast sand and railroad traction sand, and part is cleaned magnetically and used in the production of colored glass containers such as beverage bottles.

Bristol Silica and Limestone Company (18) in Jackson County produced crushed quartz for decorative granules, abrasives, poultry grit, and filtration media. Production of metallurgical silica for silicon metal was discontinued. Hanna Nickel Mining and Smelting Company produced silica from its Quartz Mountain property (12) in Douglas County for use in its nickel smelter, but with the closure of that operation, silica production has also ceased.

Soapstone for art carving was produced by Steatite of Southern Oregon (22) in southern Jackson County. The soapstone is valued particularly for its range of colors. It is shipped throughout North America, with much of the production going to Alaska, and an export market is being developed.

Ash Grove Cement West continued to quarry marble and shale near Durkee in Baker County. Shale and marble were used for the production of portland cement, and crushed marble was used in refining beet sugar in eastern Oregon and western Idaho. The total value of production from this one operation has continued to be about $25 million per year for the last five years, making the company a major source of both income and tax revenue in Baker County.

Table 1. *Active mines in Oregon, 1986*

Map no.	Name	Location	Commodity	Comments
1.	Ash Grove Cement West	Sec. 11 T. 12 S., R. 43 E. Baker County	Cement, limestone	Continued production.
2.	Clarks Creek	Tps. 12, 13 S., R. 41 E. Baker County	Au	Several small placer operations.
3.	Pine Creek	T. 12 S., R. 39 E. Baker County	Au	Several small placer operations.
4.	Deer Creek	Secs. 30, 31 T. 9 S., R. 38 E. Baker County	Au	Several small placer operations.
5.	Burnt River	T. 10 S., Rs. 35, 35½ E. Baker County	Au	Several small placer operations.
6.	Celatom	Tps. 19, 20 S., Rs. 35, 36, 37 E. Harney, Malheur Counties	Diatomite	Eagle-Picher Industries dedicated mill in Vale.
7.	Teague Mineral Products	Secs. 8, 29 T. 23 S., R. 46 E. Malheur County	Bentonite	Continued production.

Table 1. *Active mines in Oregon, 1986*—continued

Map no.	Name	Location	Commodity	Comments
8.	Teague Mineral Products	Sec. 28 T. 23 S., R. 46 E. Malheur County	Zeolite	Continued production of clinoptilolite.
9.	Camp Creek area	Sec. 4 T. 19 S., R. 21 E. Crook County	Bentonite	Continued production by Central Oregon Bentonite Co. and Oregon Sun Ranch, Inc.
10.	Oil-Dri Production Company	Secs. 14, 21, 23 T. 27 S., R. 16 E. Lake County	Diatomite	Continued production.
11.	Cascade Pumice, Central Oregon Pumice	Numerous pits in Bend area Deschutes County	Pumice	Continued production.
12.	Quartz Mountain Silica	Sec. 2 T. 28 S., R. 1 E. Douglas County	Silica	Ceased production due to closure of nickel smelter.
13.	Coffee Creek	Sec. 7 T. 30 S., R. 2 W. Douglas County	Au	Small placer operations.
14.	Nickel Mountain	Sec. 17 T. 30 S., R. 6 W. Douglas County	Ni	Closure of mine and smelter.
15.	Greenback Mine	Secs. 32, 33 T. 33 S., R. 5 W. Sec. 5 T. 34 S., R. 5 W. Josephine County	Au	Production from Irish Girl vein.
16.	Galice area	Tps. 34, 35 S., R. 8 W. Josephine County	Au	Several small placer operations.
17.	Illinois River area	T. 37 S., R. 9 W. Josephine County	Au	Several small placer operations on Briggs, Soldier, and Red Dog Creeks.
18.	Bristol Silica	Sec. 30 T. 36 S., R. 3 W. Jackson County	Silica	Continued production.
19.	Josephine Creek and tributaries	Tps. 38, 39 S., Rs. 8, 9 W. Josephine County	Au	Several small placer operations.
20.	Sucker Creek	Sec. 1 T. 40 S., R. 7 W. Josephine County	Au	Several small placer operations.
21.	Althouse Creek	Secs. 11, 12 T. 41 S., R. 7 W. Josephine County	Au	Several small placer operations.
22.	Steatite of Southern Oregon	Secs. 10, 11 T. 41 S., R. 3 W. Jackson County	Soapstone	Increased production.
23.	CooSand Corporation	Sec. 34 T. 24 S., R. 13 W. Coos County	Silica sand	Continued production of glass sand and abrasive sand.

EXPLORATION AND DEVELOPMENT ACTIVITY

Exploration activity in 1986 was generally less than in 1985. There was some exploration for industrial minerals, but most efforts were directed toward precious metals in both massive sulfide and epithermal systems. Many of the precious-metals investigations were preliminary evaluations and regional reconnaissance programs rather than drilling of specific targets.

Metals

Amselco continued exploration of the Goff Mine area (K)** massive sulfide deposit in northern Josephine County. Five holes were drilled with total footage of 3,500 ft, and the results are being evaluated.

Baretta Mines, Ltd., and Rayrock Mines, Inc., continued work on the Turner-Albright massive sulfide deposit (M) in southwestern Josephine County. The deposit was described by M.D. Strickler in the October 1986 issue of *Oregon Geology*. Uncertainties remain over the extent of post-mineralization faulting, but reserve estimates range between 2 and 4 million tons averaging approximately 0.12 oz/ton of gold, 0.60 oz/ton of silver, 1.55 percent copper, 3.70 percent zinc, and 0.50 percent cobalt.

The Almeda Mine massive sulfide deposit (L) in northern Josephine County was drilled by Kennecott, and evaluation is in progress.

Silver King Mines produced 4,000 tons of gold ore from its Iron Dyke property (A) in northeastern Baker County. The deposit is a series of massive sulfide boulders, some as large as 80 ft in diameter, entrained in a lahar. The last defined boulder is being mined out, and exploration is now directed toward locating more boulders and their in-situ massive sulfide source in areas covered by flows of the Columbia River Basalt Group.

American Copper and Nickel Company maintained its Susanville (E) precious-metal vein deposit in Grant County and is attempting to acquire a joint-venture partner to continue exploration. NERCO's Ibex property (C), part of the Bald Mountain Batholith vein system in Grant and Baker Counties, was drilled by American Copper and Nickel Company. Four diamond core holes, each about 1,000 ft deep, were drilled on the Ibex vein.

Manville International Group continued drilling and geophysical work on its Grouse Spring (D) copper-silver-zinc skarn deposit in Baker County. Manville also continued work on its Red Butte (F) sediment-hosted, epithermal, precious-metal prospect in Malheur County. The company has completed geophysical surveys and an extensive sampling program and is now in the permitting process for several drill sites.

The most intensively prospected area in Oregon has been in the volcanic-hosted, epithermal systems associated with the Quartz Mountain (I) intrusive belt in southwestern Lake County. Quartz Mountain Gold Corporation controls about 10,000 acres of this former Anaconda property and has completed over 75,000 ft of drilling, primarily on one of five rhyolite intrusives in the area. Earlier Anaconda estimates of 10-15 million tons containing 0.04 oz of gold per ton have been confirmed on this intrusive, and preliminary drilling results on a second are reported as equally encouraging. Reserve calculations, metallurgical testing, and feasibility studies for a heap leach operation are in progress.

Several other companies were active in precious-metal exploration in the state, with programs ranging through regional reconnaissance, property acquisition, sampling, and drilling. In many loca-

*(Continued on page 50, **Mineral Industry**)*

*** All letters in this section refer to "Exploration Sites" on the location map and in Table 2.*

Exploration trench for precious metals on the Quartz Mountain Gold Corporation property in southwestern Lake County.

Table 2. *Exploration sites and areas in Oregon, 1986*

Map letter	Name	Location	Commodity	Comments
A.	Iron Dyke	Sec. 21 T. 13 S., R. 45 E. Baker County	Au, Ag, Cu	Continued exploration and limited production by Silver King Mines.
B.	Dooley Mountain	Tps. 11, 12 S., R. 40 E. Baker County	Perlite	Continued evaluation by Supreme Perlite.
C.	Ibex	Sec. 4 T. 9 S., R. 36 E. Baker, Grant Counties	Au, Ag	Continued diamond drill program by American Copper and Nickel.
D.	Grouse Spring	Secs. 24, 25 T. 14 S., R. 36 E. Baker County	Cu, Ag, Zn	Continued drilling by Manville.
E.	Susanville	T. 10 S., R. 33 E. Grant County	Au, Ag	Continued evaluation by American Copper and Nickel.
F.	Red Butte	Secs. 26, 27, 34, 35 T. 25 S., R. 43 E. Malheur County	Au	Continued sampling by Manville.
G.	Alaska Pacific Oregon, Ltd.	Tps. 16, 17 S., Rs. 19, 20 E. Crook County	Bentonite	Sampling and drilling on company land east of Prineville.
H.	Tucker Hill	Sec. 35 T. 34 S., R. 19 E. Lake County	Perlite	Continued evaluation by Tenneco Minerals and Western States Minerals.
I.	Quartz Mountain	T. 37 S., R. 11 E. Lake County	Au	Drilling and trenching by Quartz Mountain Gold Corporation.
J.	Foster Creek area	Sec. 15 T. 29 S., R. 3 E. Douglas County	Soil amendment	Continued evaluation, bagging plant under construction.
K.	Goff	Secs. 20, 29 T. 33 S., R. 7 W. Josephine County	Au, Ag, Cu, Pb, Zn	Continued drilling program.
L.	Almeda	Sec. 13 T. 34 S., R. 8 W. Josephine County	Au, Cu, Zn	Drilling program by Kennecott.
M.	Turner-Albright	Secs. 3, 15, 16 T. 41 S., R. 9 W. Josephine County	Au, Ag, Zn, Cu, Co	Continued evaluation by Baretta Mines and Rayrock Mines.

Miocene *Gyrolithes* (lebensspur) from the Astoria Formation, Lincoln County, Oregon

by Guy H. Rooth, Western Oregon State College, Monmouth, Oregon 97361

INTRODUCTION

Two specimens of small (6 by 17 cm), spiral, biogenic structures were found on the beach 5 mi north of Newport, Lincoln County, Oregon. The structures consist of filled burrows within surrounding sedimentary rock. The structures are considered to be lebensspuren (traces of life), as classified by Seilacher (1953).

This paper describes these structures, compares them with similar structures from other localities, examines evidence as to the probable organism that caused them, and discusses the environmental significance of the structures.

PREVIOUS INVESTIGATIONS

Coiled marine structures similar to those from Oregon were first described and given the name *Gyrolithes* by Saporta in 1884 from Cretaceous rocks in Belgium. Since that time, similar structures ranging in age from Jurassic to Miocene have been described from several other localities throughout the world. The only other occurrence from the West Coast of the United States is from Miocene rocks of the Monterey Group, as reported by Mansfield (1930). The structures are common in some Miocene rocks of the U.S. Atlantic Coastal Plain. Miocene occurrences in North America are listed in Table 1.

The most detailed paleoenvironmental interpretation of *Gyrolithes* lebensspuren is by Gernant (1972) in a study of more than 400 samples from Miocene rocks of Maryland.

Powell (1977) has described a living polychaete worm with a similar burrow in the intertidal muds of North Carolina.

DESCRIPTION OF STRUCTURES

The two *Gyrolithes* structures from Oregon are very similar in size and geometry. They are loosely coiled, with about two coils per 10 cm of length. The coil diameter of the entire structure is approximately 6 cm, while the diameter of the burrow varies from 1.8 to 2.0 cm. The specimens are not complete, but each is approximately 17 cm long. The burrow diameters are constant throughout the structure (Figure 1).

The burrows are preserved as internal fillings of tan sandy mud that is more resistant to erosion than are the surrounding sediments. Both specimens were found on the wave-cut platform in the Moolack Beach area 5 mi north of Newport in Lincoln County, Oregon. No specimens were found in place, but Gernant (1972), after studying several hundred burrows in Maryland, reports that they are oriented upright, varying no more than 3° or 4° from bedding surfaces.

The Oregon structures agree closely with published reports. However, a few specimens reported in the literature have lengths of 30 to 40 cm (Table 1).

INTERPRETATION OF SEDIMENTOLOGICAL FEATURES

The animal that produced the *Gyrolithes* structure is not known with certainty. No remains have been found in the burrows. Nevertheless, some characteristics of the Oregon specimens, the detailed study by Gernant (1972) of the Miocene forms of Maryland, and the description by Powell (1977) of burrows made in present-day intertidal muds of North Carolina allow a probable paleoenvironmental interpretation.

The absence of several features is important. No traces of a tubelike sheath of calcium carbonate or organic matter have been found associated with any of the structures. Gernant (1972) reports that the surrounding sediments were not deformed, as would be the case with an animal forcibly displacing sediment as it burrows. The animal appears to have burrowed by excavation.

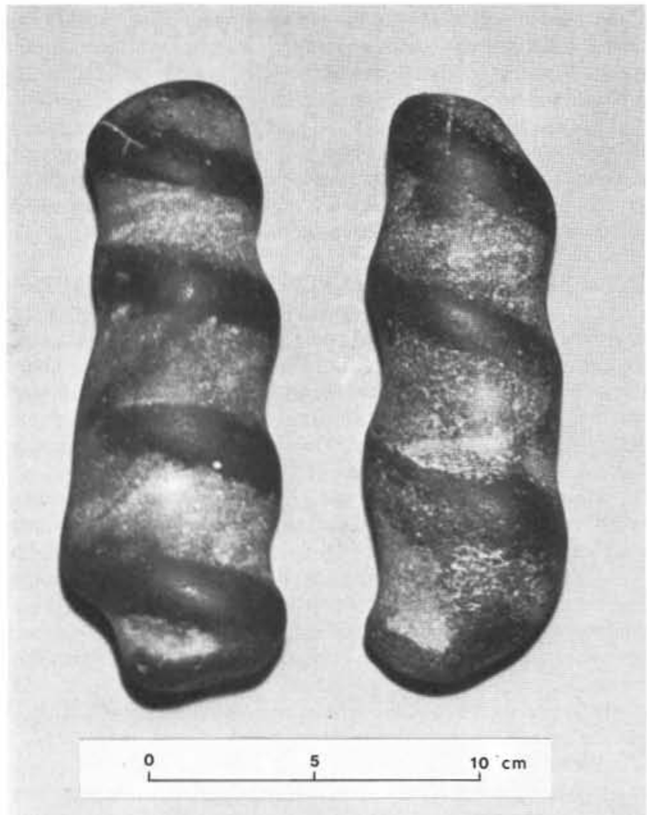


Figure 1. Fossil Miocene burrows (Gyrolithes) *from the Astoria Formation, Moolack Beach, north of Newport, Lincoln County, Oregon. Approximate size 6 by 17 cm.*

Gernant (1972) also describes and illustrates several grooves and ridges that parallel the spirally sloping burrow, suggesting that the animal that occupied the structure possessed a hard carapace or exoskeleton capable of producing continuous grooves on the outer wall of the burrow. He concludes that the evidence suggests that a burrowing crustacean occupied the burrow, rather than a softbodied wormlike animal or a symmetrical animal such as a bivalve.

Gernant notes that Schmitt (1965) described the burrowing behavior of *Myctris longicarpus* (soldier crab) as digging downward with the legs on one side of the body while rotating at the same time, so that a downward-spiraled pattern is produced. In 1972, Gernant concluded that *Gyrolithes* was made by the spiral excavations of a scavenging crustacean that repeatedly used the burrow as a "retreat." He now accepts the interpretation of Powell (1977), described in a later section of this paper, that the organism making the burrow was a polychaete worm (personal communication, 1986).

The Oregon specimens are sediment filled, whereas those studied by Gernant (1972) were not. In an attempt to obtain more information on the nature of the Oregon organism, one of the specimens was cut lengthwise to yield a cross section through the structure. It was found that the structure contained no calcareous or organic lining and that the burrow cross section is elliptical rather than circular. No trace of the actual animal was found.

The outer portion of the burrow is smooth and contains a lens of fine, tan mud. The inner wall of the burrow, which is irregular and highly disturbed, contains pieces of the surrounding sediment. No grooves could be found on the outside of the Oregon specimens due to abrasion after erosion from the bed rock.

In his paleoecologic study, Gernant (1972) indicates that the sediments and associated biofacies of the St. Leonard Member of the Choptank Formation and the St. Marys Formation suggest that the animal lived in a very shallow marine or marginal marine environment. Gernant (personal communication, 1986) has indicated, however, that some examples of *Gyrolithes* may reflect deeper water.

Because neither of the Oregon specimens was found in place, it is not possible to make interpretations based upon associated sediments or faunas. The specimens weigh 0.5 kg and were probably eroded directly from the nearby sea cliffs of the Astoria Formation somewhere in the Beverly Beach-Moolack Beach area.

INTERPRETATION BASED UPON LIVING POLYCHAETES

In the more than 90 years since the original description of *Gyrolithes* by Saporta in 1884, no one had documented a living organism with a similar burrow, until Powell (1977) attributed the structure to a polychaete worm of the family Capitellidae. He reports that two living species, *Notomastus latericeus* Sars and *Notomastus lobatus* Hartman, build spiral burrows. The spiral burrow of *Notomastus lobatus* is very similar to the fossil form *Gyrolithes.*

Powell (1977) describes the spiral burrows of *Notomastus lobatus* in intertidal muds on Banks Channel near Wrightsville Beach, North Carolina, and Sebastian Inlet, Florida, which were studied by C.E. Jenner of the University of North Carolina at Chapel Hill. The range in dimensions, based upon 27 burrows, was (1) burrow diameter, 0.5-1.1 cm, averaging 0.8 cm; and (2) diameter across the spiral, 1.9-4.0 cm, averaging 2.7 cm. The length occasionally exceeded 25 cm. The dimensions of the shaft and coil are slightly smaller than in the case of the Oregon specimens and the Miocene specimens from Maryland, but the overall geometry is nearly identical.

Powell (1977) reports that the living *Notomastus lobatus* grows to a length of 1 m and a diameter of at least 0.8 cm. Since the organism occupies the burrow throughout life, the sediments become compacted, and the burrow persists after the death of the animal.

He states that *Myctris longicarpus* (soldier crab) digs a burrow when the animal is alarmed, and that the burrow is abandoned immediately after the danger has passed. Burrows of this type are probably not stable and stand little chance of being preserved as open shafts.

CONCLUSIONS

The Miocene burrow *Gyrolithes* from the Astoria Formation of Oregon is very similar to the ones reported abundantly from the shallow-water marine rocks of Maryland. The geometry and dimensions of the structures from both localities agree closely.

The organism that produced the burrows was probably a polychaete worm, slightly larger in size but closely related to the living *Notomastus lobatus* as reported by Powell (1977). The paleoenvironmental interpretation of a shallow intertidal to sublittoral organism is supported by the sedimentological evidence of Gernant (1972) and the distribution of the living *Notomastus lobatus* as reported by Powell (1977).

In the absence of reported fossil remains within the burrows, however, the possibility that these structures were formed by asymmetrically burrowing crustaceans cannot be discarded.

The Miocene *Gyrolithes* specimens from the Astoria Formation in Oregon were probably sublittoral in origin. Gernant (personal communication, 1986) indicates that while the majority of occurrences of *Gyrolithes* are from very shallow water, some are reported from deeper water. Additional specimens from Oregon are needed to provide evidence as to the organism responsible and the paleoenvironment in which it lived.

Table 1. *Occurrence and dimensions of Miocene* Gyrolithes*

Stratigraphic unit	Location	Number	Length (cm)	Coil diam. (cm)	Shaft diam. (cm)	Source
St. Marys Fm.	Maryland	1	20.3	4.2	1.8	Mansfield, 1930
Calvert Fm.	Maryland	?	30-60	3.8	---	Dryden, 1933
Braunkohlenfm.	Germany	?	15-40	3-5	1-2	Kilpper, 1962
Choptank Fm., St. Leonard Mbr.	Maryland	100	8-16	4-5	1.5-1.8	Gernant, 1972
St. Marys Fm., Bed 22	Maryland	300	7-30	3.5-4.0	1.5-1.8	Gernant, 1972
Astoria Fm.	Oregon	2	17-18	6	1.8-2.0	This report

* *Data modified from Gernant (1972)*

ACKNOWLEDGMENTS

The author would like to thank Lowell Spring and Ray Brodersen of Western Oregon State College, Richard Thoms of Portland State University, and William Orr of the University of Oregon for reviewing the manuscript. The author is indebted to Bruce A. Spero, student at Western Oregon State College, for his loan of one of the specimens. Personal communication with Robert Gernant was also extremely helpful.

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(Maps, continued from page 42)

(DOGAMI map GMS-33), and Stayton NE quadrangle (DOGAMI map GMS-34)—the new maps cover the area extending approximately from the community of Monitor in the north to Silver Falls State Park in the south and from the community of Pratum in the west to the Molalla River in the east, showing surficial and bedrock geologic units and geologic structure on a topographic base.

In their interpretation, the authors emphasize aspects of sedimentation and paleontology and reconstruct paleoenvironments of the time period approximately 15 to 35 million years ago. At that time, this area was part of the coast along the ancient Pacific Ocean.

The study of the five quadrangles has also led the authors to the identification of a new geologic unit, which they call the Scotts Mills Formation. It is represented and described on the new maps and was presented formally in a recent article in *Oregon Geology* (December 1986 issue).

All five maps, GMS-32, GMS-33, GMS-34, GMS-50, and GMS-51, are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price for each map is $4. Orders under $50 require prepayment. □

Glimpses of DOGAMI history

John Eliot Allen, Professor Emeritus of Portland State University, was among the earliest staff members of the Oregon Department of Geology and Mineral Industries (DOGAMI). Within a year of DOGAMI's inception, he was hired by Director Earl K. Nixon as field geologist for the office in Baker and served on the DOGAMI staff for ten years. The following excerpts are from the manuscript of his autobiography, one of his latest endeavors, and from the DOGAMI Ore Bin, *in reaction to Allen's resignation, one of three that shocked the Department in one year.*

From J.E. Allen's autobiography

"When Nixon first hired me, he said, 'John, I am putting you over in eastern Oregon to compile a "Mines Handbook" of all the mines and prospects in that part of the state. I may get over to see you once every 5 or 6 months. I am paying you for your 8-hour days' work, but all your advancement and promotion will depend upon two things: one, the number of new ideas you come with and two, the amount of overtime you put in.' This is the best simple formula for success I have ever heard, and I have tried to follow it throughout my career.

"The Baker office was located in a small one-story building on Court Street and consisted of a small front office, two cubbyholes for Leslie Motz, the assayer and chemist, and myself, and a slightly larger room for the assay laboratory. Albert Quine, whom I succeeded, had left to take charge of the Cornucopia Mine operations. I spent much of my time in the field, coming in for weekends and a day or so for report-writing. During my 2 years in Baker, I visited and wrote reports on 335 mines and prospects east of the Cascade Range in Oregon. . .

"On one of my very first mine examinations, I visited a small free-gold property on Chicken Creek, northwest of Homestead. It had a drift about 300 feet long on a narrow quartz vein of free-milling gold. But the geology was quite complicated, since the vein cut serpentine, gabbro, porphyritic andesite, and a large granodiorite dike.

"The miner was digging with a pick and shovel, moving the ore and waste with a wheelbarrow, and at the end of the dump he had erected a one-stamp mill operated by a one-lunger gas engine, the fines flowing out over an amalgamated copper plate. He was producing $15-20 per day, and the 2- to 5-inch vein probably ran several hundred dollars a ton in free gold.

"In mapping the mine, I had collected quite a suite of rock specimens and was sitting on the dump with the miner, examining them in the daylight, and telling him all the names of the variety of rocks I was proudly able to identify. I noticed that he was apparently getting more and more restless, and finally his face got red and he burst out: 'There's only two kinds of rock in my mine — bin rock and dump rock!'

"This was a very good initiation for a budding economic geologist, and I have used the story for many years in my classes. I later heard an equivalent story from a construction engineer — who must learn to distinguish between 'clink rock' and 'clunk rock'."

From the *Ore Bin*, v. 9, no. 8, August 1947

"Department Loses Geologists. Three geologists occupying key positions in the Department have resigned to accept better jobs. Their leaving brings home a condition in the country which was confidently predicted in educational and scientific circles, but was given little attention by those in authority during the war.

"Young scientists were grabbed by the draft and in many instances put into service bearing little relation to their training and possible future use to the country. As a consequence, they lost three or four years of training work in their professions, causing a present shortage of those qualified to carry on scientific investigations and research. This shortage is accentuated by the large increase in enrollment at institutions of higher learning and the increased need for teachers, especially those qualified to teach science and engineering. The shortage, of course, has resulted in bidding (in which the Federal Government has participated) for qualified men, which leaves relatively small agencies like the Department, whose salary ranges are pretty well fixed by law, out in the cold. Such small departments are not able to fill vacancies immediately by promotion, and must suffer a setback in work on projects which are interrupted by resignations.

"Dr. Wallace D. Lowry left the Department on August 1st to take a position in California as geologist with the Texas Company.

"Dr. Ewart M. Baldwin has accepted the position of Assistant Professor of Geology, University of Oregon, at Eugene. He is leaving the Department early in September.

"Dr. John Eliot Allen, department geologist for ten years, is leaving in September to become Associate Professor of Geology at Pennsylvania State College." □

John E. Allen (left) mapping and surveying in the Wallowa Mountains (?) in 1938-1939, together with Leslie Motz, assayer and chemist at the Baker field office. Photo from DOGAMI files.

Metals and Minerals Conference to be held in Portland

The 33rd Annual Pacific Northwest Metals and Minerals Conference will be held in Portland, Oregon, Monday and Tuesday, April 27-28, 1987, at the Red Lion Inn, Lloyd Center. It is jointly sponsored by the local sections of AIME, AWS, ASM, and AIChE.

The 1987 Conference theme will be "Modern Mineral and Metal Technology," emphasizing recent developments and emerging technologies that affect the future direction of the minerals and metals industry.

The conference will begin with a Monday morning Keynote Session in which Robert C. Horton, Director of the U.S. Bureau of Mines, Gerard A. Drummond, President, Nerco Inc., and Karl W. (Bill) Mote, Executive Director, Northwest Mining Association, will address the outlook for metals and minerals industries in the Northwest. At the conference luncheon on Tuesday, Mr. Maynard Miller, Dean, University of Idaho Mines and Resources, will present the academic viewpoint on the future of the metals and minerals industry.

The two-day conference will include 12 technical sessions that address recent technological developments in welding and joining, physical metallurgy, geology, small mining, regional mineral resources potential, pyrometallurgy, hydrometallurgy, and chemical processing. Summaries of the latest results of ongoing research and emerging technologies will be presented in Monday and Tuesday afternoon poster sessions. At one of the Monday afternoon technical sessions, five speakers will address the geological and technical characterization of the sites for a high-level nuclear waste repository. On Tuesday morning one of the technical sessions will highlight four talks addressing nuclear waste disposal technology.

A popular feature of this conference is the "Industrial Trade Exposition" held in conjunction with the regular program. A full slate of social activities, including varied local activities for spouses, will round out the conference. Additional information can be obtained from Charles B. Daellenbach, P.O. Box 70, Albany, OR 97321, phone (503) 967-5833. *—PNMMC news release*

***(Mineral Industry,** continued from page 46)*

tions, companies are evaluating their preliminary surveys and are in the process of consolidating their land positions.

Industrial minerals

Relatively little exploration activity for industrial minerals was evident in 1986. Exploration for zeolites was minimal, due in part to continued difficulty in generating large-volume markets for natural zeolites and in part to numerous corporate reorganizations in the mineral exploration business as a whole. Several zeolite deposits have been drilled in recent years, and most are still held by various companies attempting to develop markets.

Supreme Perlite continued exploration of perlite deposits on Dooley Mountain (B) in Baker County. Tenneco Minerals, in a joint venture with Western States Minerals, has completed testing of a perlite deposit on Tucker Hill (H) in Lake County. The deposit is of excellent quality, but its location with respect to transportation and markets is a disadvantage.

Endurance Minerals is evaluating hydrothermally altered volcanic rocks in the Foster Creek area (J) of southeastern Douglas County for use as a soil amendment and micronutrient source. A bagging plant is under construction, and field testing of the product is continuing.

Alaska Pacific Oregon, Ltd. (G), conducted a bentonite sampling and drilling program on its land east of Prineville in Crook County. Teague Mineral Products continued to block out further reserves of bentonite associated with its mining operation in Malheur County. □

WSA evaluations continue in Oregon

U.S. Geological Survey geologists will be conducting geological studies of the following Bureau of Land Management Wilderness Study Areas (WSA) during 1987 as part of the WSA evaluation process. Persons with any questions, comments, or additional information on mineral resources within these areas are urged to contact Floyd Gray, U.S. Geological Survey, MS 901, 345 Middlefield Road, Menlo Park, California 94025, phone (415) 323-8111, extension 4141.

WSA name	Oregon WSA number
Lakeview District	
Devil's Garden Lava Bed	OR-001-002
Squaw Ridge Lava Bed	OR-001-003
Four Craters Lava Bed	OR-001-022
Diablo Mountain	OR-001-058
Orejana Canyon	OR-001-078
Abert Rim	OR-001-101
Fish Creek Rim	OR-001-117
Guano Creek	OR-001-132
Spaulding	OR-001-139
Hawk Mountain	OR-001-146A
Burns District	
Malheur R.-Bluebucket Cr.	OR-002-014
Sheepshead Mountains	OR-002-072
Wildcat Canyon	OR-002-072D
Table Mountain	OR-002-072I
East Alvord	OR-002-073A
Alvord Desert	OR-002-074
Pueblo Mountains	OR-002-081
Rincon	OR-002-082
High Steens	OR-002-085F
Home Creek	OR-002-085H
Blitzen River	OR-002-086E
Little Blitzen Gorge	OR-002-086F
Vale District	
Camp Creek	OR-003-031
Cottonwood Creek	OR-003-032
Dry Creek Buttes	OR-003-056
Upper Leslie Gulch	OR-003-074
Slocum Creek	OR-003-075
Honeycombs	OR-003-077A
Lower Owyhee Canyon	OR-003-110
Jordan Craters	OR-003-128
Willow Creek	OR-003-152
Disaster Peak	OR-003-153
Fifteen Mile Creek	OR-003-156
Oregon Canyon	OR-003-157
Twelve Mile Creek	OR-003-162
Upper West Little Owyhee	OR-003-173
Owyhee Canyon	OR-003-195
Prineville District	
Thirtymile	OR-005-001
Lower John Day	OR-005-006
North Pole Ridge	OR-005-008
Spring Basin	OR-005-009
Badlands	OR-005-021
South Fork	OR-005-033
Sand Hollow	OR-005-034
Sheep Mountain	OR-006-003
Medford District	
Mountain Lakes	OR-011-001
Coos Bay District	
North Sisters Rock	OR-012-008
Zwagg Island	OR-012-014

□

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GMS-16: Free-air gravity anomaly map and complete Bouguer gravity anomaly map, south Cascades, Oregon. 1981	3.00		
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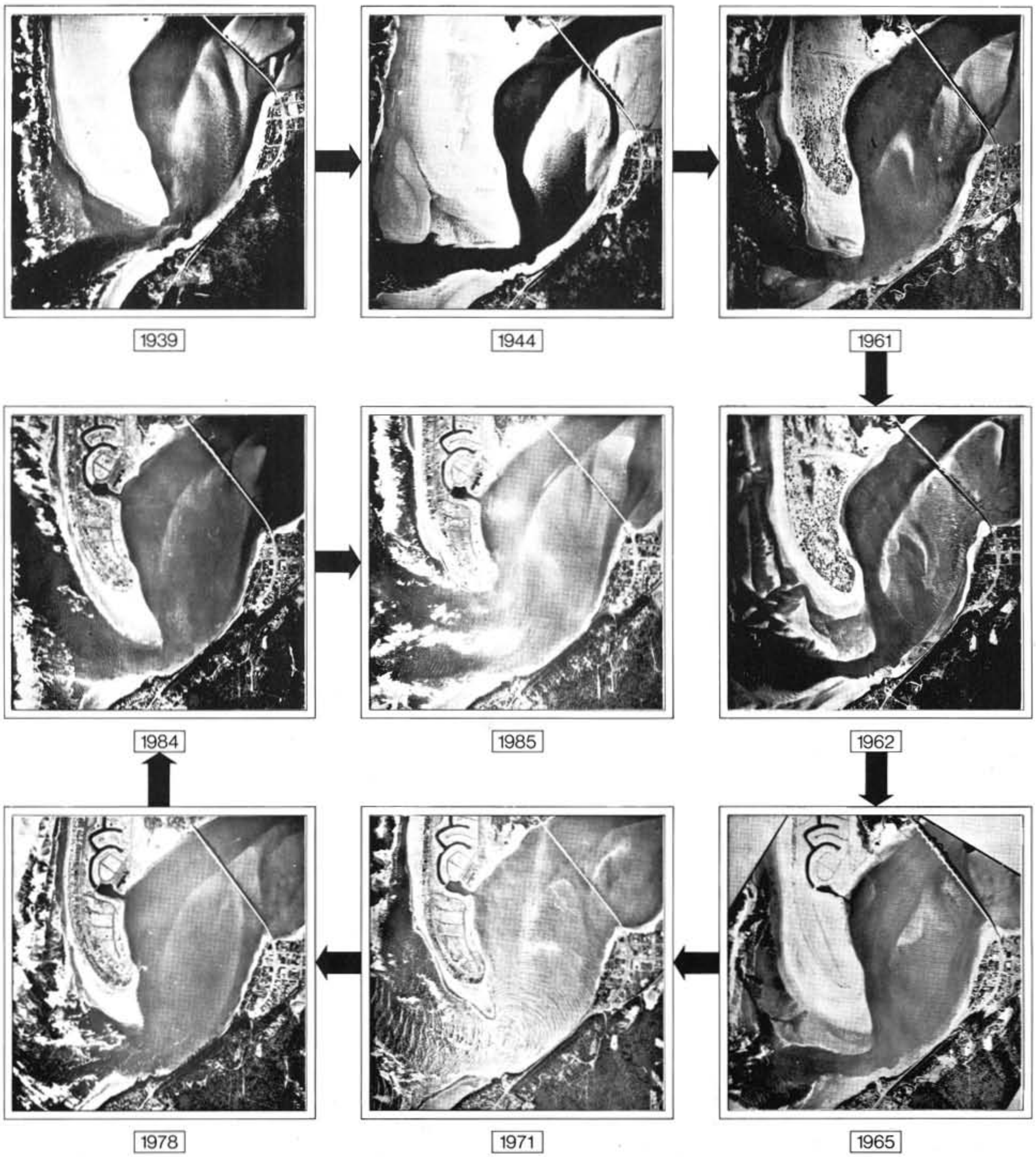

THIS MONTH:
Erosional changes at Alsea Spit, Waldport

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors*, 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Selective chronological photo record of changes at Alsea Spit, Waldport, Oregon, from 1939 to 1985. Article beginning on next page discusses changes at this location that were attributed to "El Nino" of 1983.

OIL AND GAS NEWS

Gas injection begins at Mist

Oregon Natural Gas Development began to inject gas into the Bruer Pool on February 11 at the natural gas storage project at Mist Gas Field. During February, a total of 234,125 Mcf of gas was injected, using the injection-withdrawal well IW 32d-10, located in NE¼ sec. 10, T. 6 N., R. 5 W. Plans are to repressurize the gas reservoir to about 25 percent of the original pressure, or some 725 psi, and reduce water influx into the pool. The first withdrawal is planned to occur this fall, depending on market conditions. Injection into the Flora Pool began during March using the injection-withdrawal well IW 33c-3, located in SE¼ sec. 3, T. 6 N., R. 5 W.

NWPA annual symposium scheduled

The Northwest Petroleum Association (NWPA) has scheduled its annual symposium for May 18 and 19 at the Riverhouse Motor Inn, Bend, Oregon. The meeting will focus on the Columbia Basin and Plateau geology and hydrocarbon potential and will include a talk on current geothermal activity in Oregon. A field trip is planned to the Mitchell area, and speakers will discuss tectonics, stratigraphy, geophysics, leasing activity, and other subjects of interest. Information can be obtained from Phil Brogan, (503) 382-0560, or the NWPA, P.O. Box 6679, Portland, OR 97728. □

GSA to hold 1987 Annual Meeting in Arizona

Phoenix, Arizona, will be the site of the 1987 Annual Meeting of the Geological Society of America (GSA) October 26-29. It is the first time that the Society has met in Arizona and thus represents the first official, comprehensive coverage of the geology of Arizona by one of the world's largest earth science meetings. Twenty-seven symposia will address topics from the geology of human origins and cultural evolution to the geology in China. Thirty-four field trips before and after the meeting will explore the southern Colorado Plateau and Basin and Range. There will even be two exciting Colorado River float trips. Subjects of the eight new short courses sponsored by the Society include contaminant hydrogeology, paleoseismology and active tectonics, planetary geology and remote sensing, and site characterization for high-level nuclear waste disposal.

The 200-booth technical geoscience exhibit will include the newest and finest in computer hardware and software, spectroscopes, microanalysis and X-ray diffraction equipment, cameras, maps, publications, and field supplies. GSA will also offer its popular employment service, which is open to both employers and job seekers. For further information, contact Nancy Reed at GSA headquarters, (303) 447-2020. □

South Carolina accepting applications for Geologist and GIT Grandfathers

Geologists and geologists in training seeking registration **without examination** in South Carolina must submit application and fees by June 10, 1987 (postmarked). Application packets are available for $5.00 from South Carolina Board of Registration for Geologists, 1213 Lady Street, Suite 201, Columbia, SC 29201, phone (803) 253-6498. □

New USGS phone number listed

The U.S. Geological Survey, Western Region, Menlo Park, California, has changed to a direct-dial telephone system.

Effective April 1, 1987, the Public Affairs Office, Western Region, will have the following phone number: (415) 329-4000. □

Erosional changes at Alsea Spit, Waldport, Oregon

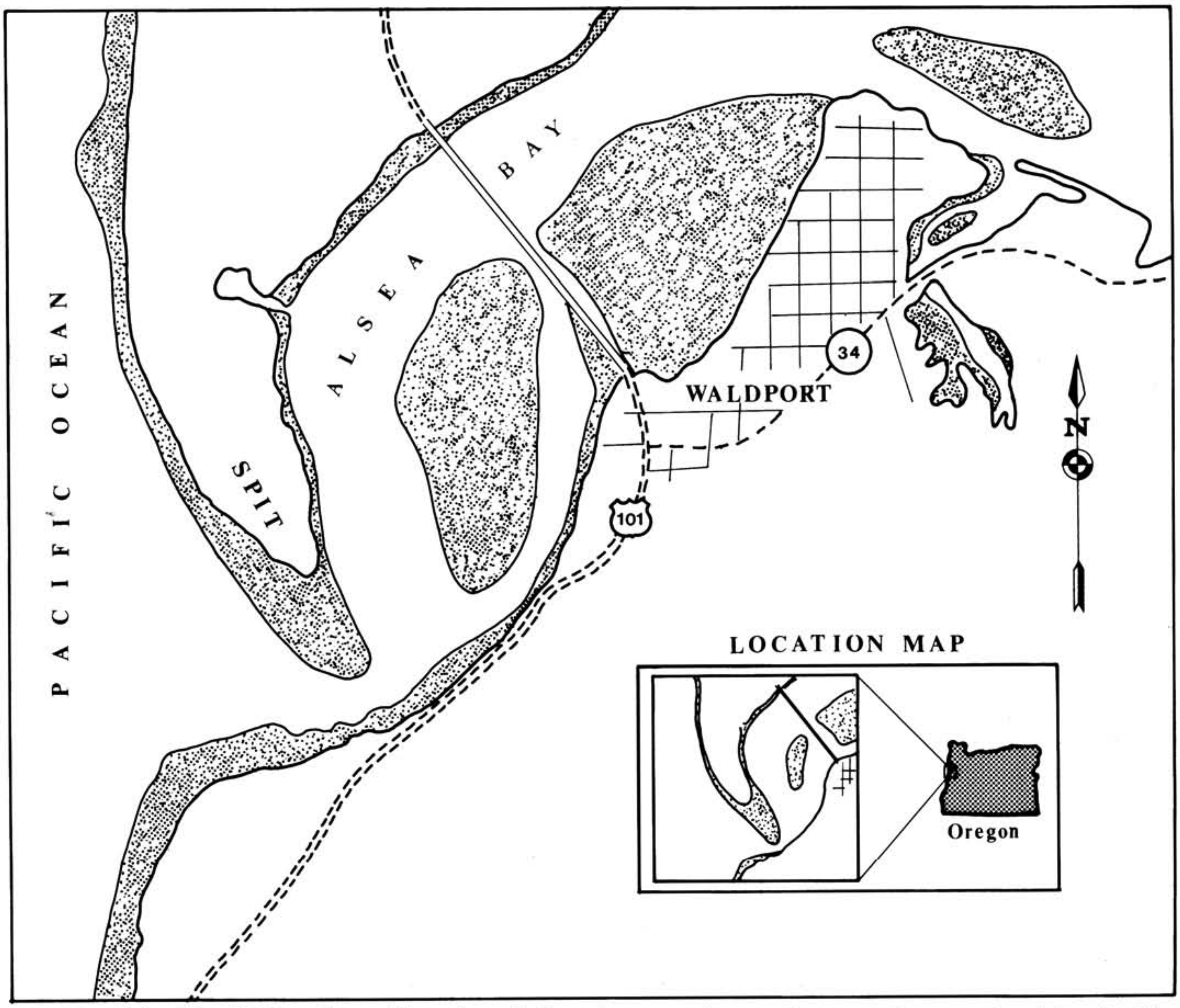
By Philip L. Jackson, Assistant Professor, and Charles L. Rosenfeld, Associate Professor, Department of Geography, Oregon State University, Corvallis, Oregon 97331.

INTRODUCTION

Marine erosion that was attributed to the effects of the 1983 "El Nino" resulted in the loss of the distal tip of Alsea Spit in 1985. Within a five-week period, the inlet to Alsea Bay opened to a width of over 1,900 ft (580 m), quadrupling the previous cross-sectional area of the channel, and subjecting the City of Waldport to increased flooding risk from winter-season high tides and storm events.

In October 1985, a study team was assembled at Oregon State University (OSU) in response to a request from Lincoln County. This resulted in intensive monitoring of marine erosion and flood potential over the subsequent 18 months. As erosion rapidly claimed the distal tip of Alsea Spit and threatened to undermine homes on the perimeter of Bayshore Subdivision, the County Board declared an emergency and appealed to state and federal agencies for technical and financial assistance. Law prohibits the use of state or federal funds for structural mitigation measures outside incorporated areas, so the Governor, acting on the best information available, declared an emergency but could not offer direct financial assistance. It was immediately apparent that the City of Waldport was in jeopardy of increased flood risk, since the spit had previously served as a barrier to direct wave attack and storm surge. With substantially heightened risk to people and property, the focus of the hazard evaluation turned to the city, where some homes are sited at 10 ft above mean sea level* (+10 ft [3 m] MSL), and some commercial buildings on U.S. Highway 101 (Main Street) are at only +12 ft [3.6 m] MSL. An intensive surveying and field monitoring effort was carried out

* *Average elevation of sea surface for all tide stages recorded over a 19-year period.*



Map of Alsea Spit at Waldport, Oregon. Textured areas indicate migratory sand areas under current, shore-normal conditions. Graphics by Doug O'Neil.

to provide data and information that would help to understand the dynamics of the situation and provide the basic findings for proposals seeking federal emergency assistance for protective structures.

A computer model of tidal channel dynamics was used to estimate marine flood potential, and a monitoring effort has kept watch over changing inlet conditions. The rate of spit recovery has been documented, and the information gathered provides a continuous record of the temporal and spatial scale of the erosion episode (Jackson and others, 1986).

By December 1985, the Alsea Bay inlet had widened to its maximum extent. Homes on the spit protected by rock revetments were isolated on peninsulas between unprotected vacant lots.

PROCESSES OF CHANGE

The configuration of Alsea Spit and the inlet to Alsea Bay have remained relatively constant since the first reliable topographic maps of the area were published in 1914. This consistency of form is primarily due to the regularity of seasonal coastal processes that have yielded a zero net littoral drift. The southwest winter-storm cycle erodes old marine terraces and beaches, causing the development of nearshore sandbars and a significant northward transport of sediment by longshore currents. The milder seas of summer produce nearly continuous northwest wave swells that gradually push the sand back onto the beaches with a southerly drift that virtually cancels the effects of winter storms (Schlicker and others, 1973). Under these conditions, the position of Alsea Spit and the configuration of the inlet have varied only seasonally, with the principal tidal flow maintaining a bedrock-confined channel close to the south shore of the bay (RNKR Associates, 1977). Previous reports described Alsea Spit as a prograding spit. Stembridge (1975) observed accretion averaging 10 ft (3 m) per year over several decades. The cover photo provides a selective chronological photo record of changes from 1939 to 1985.

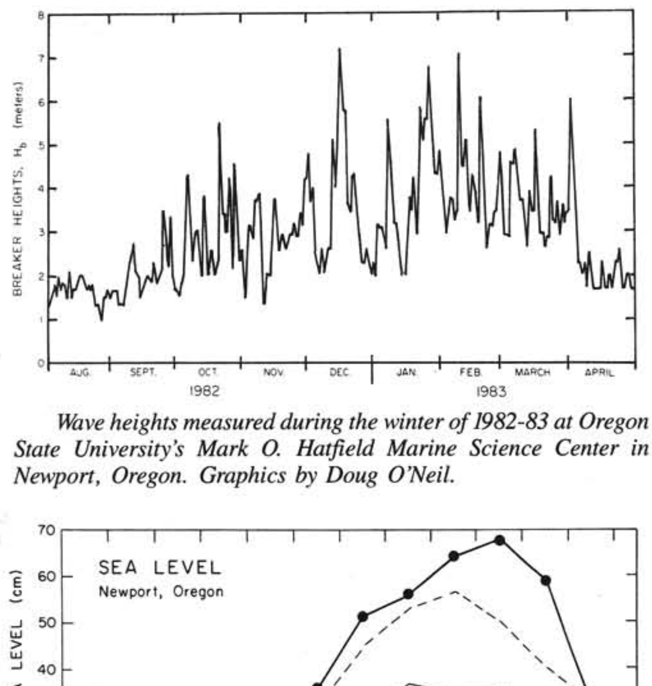
The El Nino-Southern Oscillation (ENSO) event that generally lasted from April 1982 through July 1983 pushed a "bulge" of warm water up along the west coast of the United States, disrupted Pacific Coast weather norms, and resulted in higher than normal sea levels. The magnitude of the weather anomaly was ranked among the most significant of this century. While many elements of the ENSO event immediately contributed to Oregon coastal erosion, some had latent effects as well.

A simultaneous rise in sea level and the increased frequency of high-energy storm wave conditions are known to have contributed directly to severe erosion and property damage during the winter of 1982-83. Breaker heights on the order of 23 ft (7 m) were recorded on the OSU Marine Science Center microseismometer at Newport during three major storm events (see graph of wave heights). These major storms struck the coast at about the same time when sea level was near maximum (see graph showing sea levels) and when annual astronomical tides were strongest. High tides during the December 1982 storm reached 11.0 ft (3.3 m) above mean lower low water** (+11.0 ft [3.3 m] MLLW), 1.9 ft (0.5 m) higher than the predicted level. A January 1983 storm brought a tide level reaching to +12.4 ft (3.8 m) MLLW, 2.8 ft (0.8 m) higher than expected, and a February 1983 storm tide measured 1.4 ft (0.4 m) above that predicted. All these tide events are exceptional for the Oregon coast (Huyer and others, 1983; Komar, 1986).

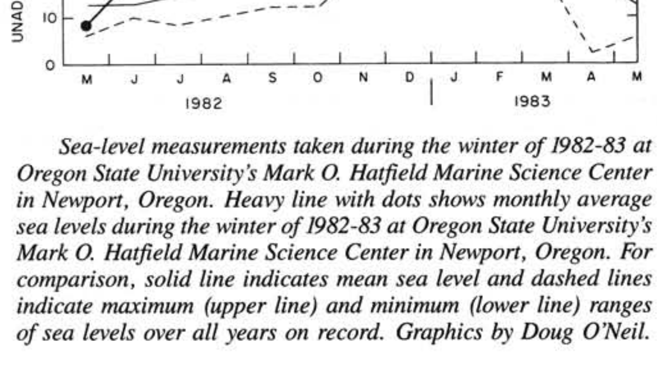
The ENSO effect is triggered by a breakdown of tradewinds in the western Pacific that allows a "bulge" of warm water to move eastward along the equator, until the "bulge" splits at the coast of South America. The northern portion travels along the continental shelf, held along the coast by wave refraction and the Coriolis force. This eventually raises sea levels along the west coasts of Mexico and the United States for periods of up to six months.

The winter storms of 1982-83, accentuated by El Nino, were a nightmare for residents of Alsea Spit. The powerful northward longshore drift, accompanied by sediment from freshly eroded beaches and terrace deposits to the south, produced a massive sandbar along the south shore of the bay mouth. This effectively deflected the discharge from the bay northward, cutting a channel close to shore along the distal tip of the spit. This allowed the big storm

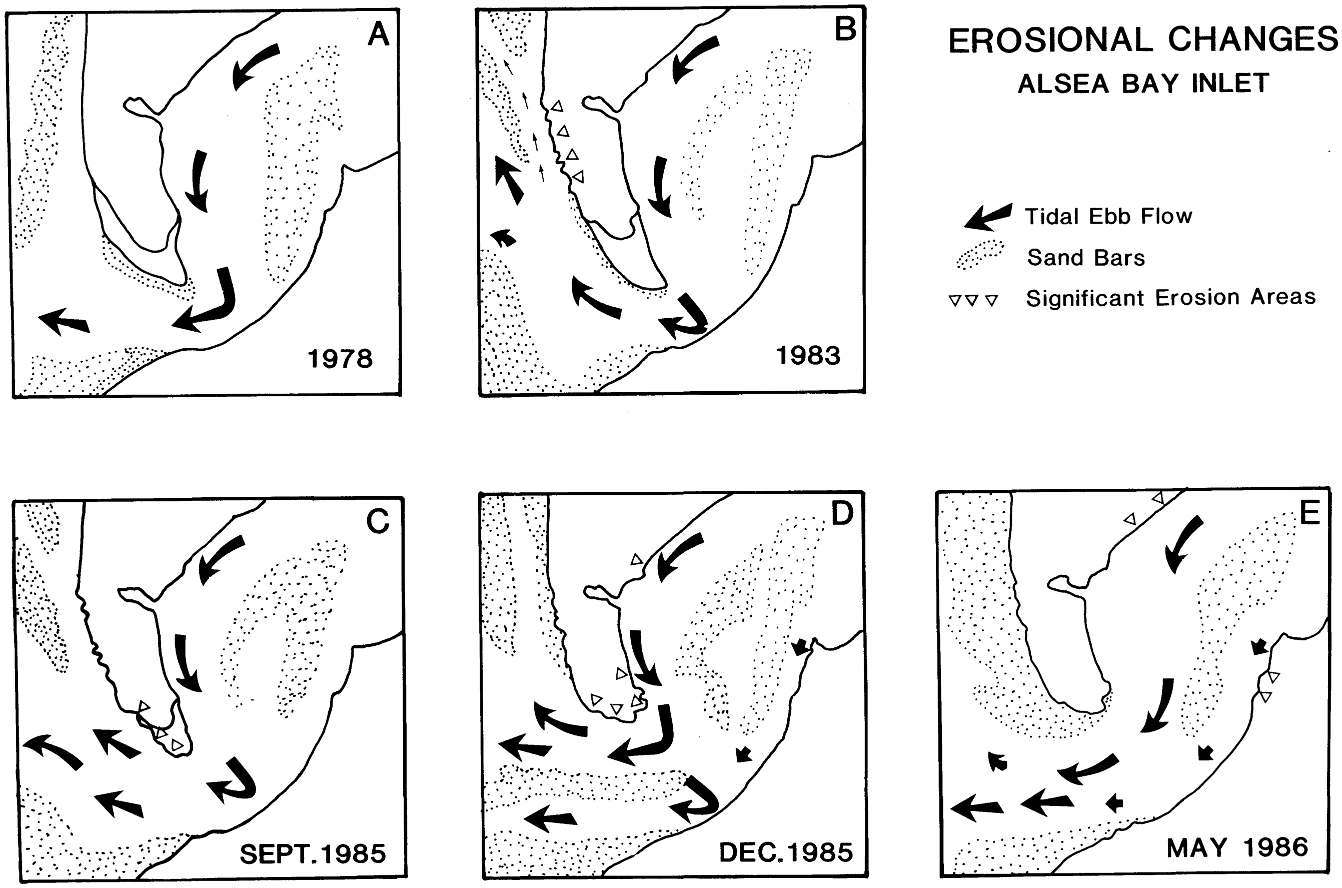
*** Calculated elevation standard derived from average of 19-year recording period. For area discussed here, MLLW = MSL-4.1.*



Wave heights measured during the winter of 1982-83 at Oregon State University's Mark O. Hatfield Marine Science Center in Newport, Oregon. Graphics by Doug O'Neil.



Sea-level measurements taken during the winter of 1982-83 at Oregon State University's Mark O. Hatfield Marine Science Center in Newport, Oregon. Heavy line with dots shows monthly average sea levels during the winter of 1982-83 at Oregon State University's Mark O. Hatfield Marine Science Center in Newport, Oregon. For comparison, solid line indicates mean sea level and dashed lines indicate maximum (upper line) and minimum (lower line) ranges of sea levels over all years on record. Graphics by Doug O'Neil.



Erosional changes at Alsea Spit and Alsea Bay inlet. Graphics by Doug O'Neil.

waves to attack the spit unimpeded by shallow water (see figure showing erosional changes, for a chronology of significant tidal channel changes and erosion areas). The result was catastrophic, as erosion cusps narrowed the spit by over 200 ft (656 m) in places (Erosional Changes Map B). Residents fought back with hastily placed riprap, which was quickly "swallowed up" by high wave energy.

The channel deflection resulted in a steep foredune face all along Alsea Spit that slumped and eroded with each succeeding storm event. Some homeowners placed riprap on the eroding shorefront and succeeded in stabilizing the foredune beneath their structure, but adjacent unprotected lots eroded away, leaving the homes perched — often with oceanfront doors that opened to a 25- to 30-ft (7.6-9 m) drop to the beach, a condition that actually resulted in an injury to a resident! Ultimately, one house was lost, and several remain perilously close to the erosion bluff.

Predominant northwest sea swells in summer 1985 gradually pushed the nearshore sandbar back toward the beach with a gentle southward drift. This activity gradually dismantled the large sandbar deflecting the ebb current of Alsea Bay, but in doing so exposed the southern tip of Alsea Spit to nearly direct wave attack (Erosional Changes Map C). From August to November 1985, the tip was eroded to a narrow taper. The mass of sand moved north by El Nino spread out and choked the narrow but deep channel with more sand than the ebb tide could flush out.

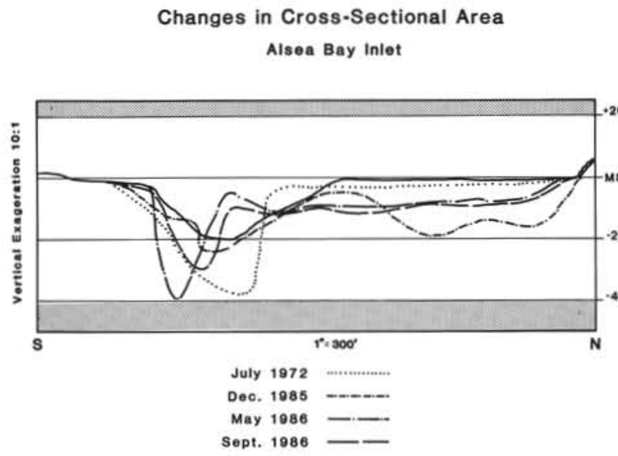
In this situation, tidal action became critical. No longer confined to a narrow but deep (40-ft [12-m]) channel, the peak velocities of the flood and ebb tides cut laterally into the soft spit on the north side of the inlet. Between September and November 1985 (Erosional Changes Map C), the inlet width increased from 400 ft (122 m) to nearly 1,900 ft (580 m). Two distinct channels, each nearly 20 ft (6 m) deep, occupied the flanks of the inlet.

With the onset of the 1985-86 winter-storm season, the harsh reality of the changes became evident. Wave attack on the residential areas at the tip of the spit was brutal. Rocks large enough to form an effective revetment against the waves were unfortunately also heavy enough to sink as a result of hydraulic "pumping" of the sands by those same waves.

EFFECTS OF CHANGES IN THE TIDAL INLET

The cross-sectional area of the tidal inlet has changed significantly since bathymetry was measured by the OSU Ocean Engineering Department in 1972. In 1972, the cross section of the inlet channel at its narrowest point with a width of 259 ft (79 m) was 5,520 ft^2 (513 m^2), a shape that remained nearly constant until September 1985. By December 12, 1985, the inlet area had increased to 21,789 ft^2 (2,025 m^2), an increase of almost 400 percent. This dramatic change in cross-sectional area was assumed to have the effect of increasing the amount of ocean water entering the bay at high tide. To predict the likely flow characteristics and sea-surface elevations resulting from the changes in inlet area and configuration, the investigators decided to adapt the Tidal Inlet Hydraulics Model to computers at OSU. Scientists of the Coastal Engineering Research Center (CERC) at the U.S. Army Corps of Engineers Waterway Experiment Station at Vicksburg, Mississippi, cooperated in the installation of the model and in the review of the findings (Sorenson, 1978; CERC, 1984). A wide range of ocean-bay configurations were simulated on the basis of 1972 and 1985 field data.

The findings of the model indicate that the peak tidal flux, or water flow through the inlet due to tidal change, increased from a 1972 value of 30,790 ft^3 (872 m^3), per second to 49,600 ft^3 (1,405 m^3), per second in 1985, an increase of over 62 percent. At this rate of flow, the channel volume exceeds the maximum recorded



Date:	July 1972	Dec. 1985	May 1986	Sept. 1986	Jan. 1987
Cross Sectional Area:	513 m²	2025 m²	1527 m²	1591 m²	912 m²

Changes in cross-sectional area of Alsea Bay inlet between 1972 and 1987. Graph shows changes in shape; table presents corresponding measurements of cross-sectional area. Graphics by Doug O'Neil.

Swirling tidal eddies gouge erosional cusps along the tip of Alsea Spit, while homeowners battle the severe loss of property with basalt riprap.

discharge of the Alsea River (38,850 ft³ [1,100 m³] per second). The mass transport of water across the outer bar due to wave action or storm surge is also enhanced and tends to raise the sea-surface elevation and increase the flow rate through the inlet. The normal cross-sectional area of the tidal inlet acts as a valve restricting the flow of tidal water into the bay. Under the pre-1985 inlet configuration, the ratio of bay-surface to sea-surface elevation is calculated at 0.71, i.e., a +10-ft (3-m) tide would raise bay-surface elevation to slightly over 7 ft (2 m). This ratio was measured in 1972 and accurately predicted by the tidal inlet model under 1972 conditions. With a large inlet, such as that observed in 1985, the ocean-to-bay ratio is 1.00. Detailed calculations for Alsea Bay indicate that under a range of conditions, each high-tide cycle could result in up to 2.4 ft (0.7 m) higher bay-surface elevations than in 1972—water levels effectively above the height of previously installed riprap and shoreline protection. As long as the ocean-to-bay ratio remains at 1.00, storm surge and wave setup can increase bay elevations in excess of the predicted tidal levels. This means that more water enters and exits the bay at each tidal cycle, and the direct result is increased erosion of the interior of the bay. One focus of erosion has been observed along the Maple Street area in Waldport from the Alsea Bay bridge west to the sea wall (Erosional Changes Map E). Bank retreat in some areas measures over 30 ft (9 m), and in one section, decayed cedar pilings were exposed. The presence of the pilings raises speculation that the eroded area may have been old earthen fill and therefore more easily lost to high water and wave action. Another extensive zone of erosion is found on the north shore from the bay bridge to west of the Bayshore Inn (Erosional Changes Map E). Here a concrete boat ramp was undercut and destroyed by erosion. The shoreline in this area has been cut back by 35-50 ft (10-15 m) into unconsolidated sand and buried log debris. Tidal ebb continues to form erosional cusps in reaches of unprotected shoreline along the bay side of Alsea Spit from the Bayshore Inn to the inlet.

The model of ocean-bay interaction indicates that flood risk to Waldport was significantly increased by the enlarged inlet configuration during the winters of 1985-86 and 1986-87. The West Coast winter-storm period (November-February) happens to coincide with the highest astronomic tides (spring tides) of the year. Our calculations based on winter 1985-86 conditions with an inlet area in excess of 16,000 ft² (1,500 m²), indicate that a 100-year storm event could generate tides and wind-driven waves of sufficient magnitude to cause substantial flooding to the greater portion of Waldport. Under these extreme conditions, ocean swells would carry into the bay, and breaking waves would have greater runup potential, causing especially severe damage to the Maple Street area (Holman, 1986).

PRESENT STATUS

Bathymetric profiles indicate that sand is presently being redistributed into the inlet area (see figure showing cross-sectional changes). A sandbar is building southward from the distal tip toward the main channel. Submerged at high tides, the bar is exposed at mean sea level for more than 490 ft (150 m) to the south. January 1987 bathymetry shows an inlet cross-sectional area of slightly less than 10,750 ft² (1,000 m²), the smallest inlet area recorded since the 1985 erosion episode began. The calculated ocean-to-bay ratio has also dropped to 0.93, indicating that the present inlet configuration is acting to somewhat restrict tidal flow through the inlet. The inlet bar is subject to hydraulic scour at flood and ebb, but the recent trends indicate a relatively rapid net growth in the bar. A south channel maximum depth of -40 ft (-12 m) MSL was recorded in January 1986, and an observation dive in the channel indicated that the channel was scoured to bed rock. January 1987 bathymetry shows a main channel maximum depth of only -23 ft (-7 m) MSL with a sand bottom. It appears that as long as the south channel remains clogged, the inlet bar will continue to suffer erosion and scour and thus rebuild at a slow rate. However, the presence of sand in the south channel indicates that a net southward migration of sand is taking place within the littoral cell.

Nearly five years after elevated sea levels and heavy storm surf stripped sand from Alsea Spit and transported it northward, the Alsea Bay inlet continues to remain in disequilibrium. Using O'Brien's equations for determining the stability of inlet channels and adjusting them to the empirical data for West Coast bays, the cross-sectional area of Alsea Bay inlet should be stable at between 4,200 and 5,900 ft² (450 and 550 m²) when in equilibrium (O'Brien, 1969). The effects of the severe ENSO event linger far beyond the norm of balanced sand transport due to seasonal reversals of longshore currents. Close monitoring of inlet configuration over 18 months leads us to conclude that the temporal scale of the ENSO event may be on the order of a decade. Research presently under way seeks to link the detailed monitoring of Alsea Bay inlet with contemporary

An older home succumbs to wave erosion along the Waldport bay front. This event occurred during a moderate high tide but without strong wave activity.

findings regarding erosion and transport throughout the Yaquina Head-to-Cape Perpetua littoral cell, with the ultimate objective being a better understanding of transport processes. This is seen as the first step in developing a predictive model of long-term shoreline change for the Oregon coast.

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New geologic maps for northern Deschutes basin released

Three new geologic maps released by the Oregon Department of Geology and Mineral Industries (DOGAMI) describe the structure and geology of the northern Deschutes basin in Jefferson and Wasco Counties.

The three maps cover a total of six adjoining 7½-minute quadrangles, an area that stretches along the Deschutes River from its confluence with the Warm Springs River in the north to Lake Simtustus in the south and includes the southeastern portion of the Warm Springs Indian Reservation.

Prepared by Gary A. Smith, formerly of Oregon State University and now the University of Arizona, the two-color maps (scale 1:24,000) have been published in DOGAMI's Geological Map Series as map GMS-43, *Geologic Map of the Eagle Butte and Gateway quadrangles, Jefferson and Wasco Counties, Oregon;* map GMS-44, *Geologic Map of the Seekseequa Junction and a Portion of the Metolius Bench Quadrangles, Jefferson County, Oregon;* and map GMS-45, *Geologic Map of the Madras West and Madras East Quadrangles, Jefferson County, Oregon.*

The combined maps show, for the first time, the extent of a newly identified rock unit, the Simtustus Formation, which is 12 to 15.5 million years old. Geologist Smith had formally named and described the new formation in a recent issue of *Oregon Geology* (v. 48, no. 6, June 1986). GMS-43, -44, and -45 are also the first detailed geologic maps of those areas that lie within the Warm Springs Indian Reservation.

Together the three maps identify and describe the geologic structure of the area, five units of unconsolidated deposits, and 22 rock units of Tertiary age, the oldest being approximately 35-40 million years old. In the southern portion of the area, on maps GMS-44 and GMS-45, a special symbol also identifies prominent exposures of deposits derived from eruptions of Mount Jefferson. A time rock chart and a geologic cross section complete the information provided on each map sheet.

The new maps, GMS-43, GMS-44, and GMS-45, are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5528. The purchase price for each map is $4, and the entire set of three maps may be purchased for $10. Orders under $50 require prepayment. □

Directory of mineral producers in Oregon now available

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new compilation of the State's mineral producers.

Directory of Mineral Producers in Oregon has been published as DOGAMI Open-File Report O-87-3. It was derived from a Departmental computer listing of approximately 800 records, originally designed for internal use.

The new directory presents these records in two tables, one arranged by commodity, the other by county. The commodity grouping of Table 1 includes over 30 commodities—from "Abrasives" to "Zeolite"—and lists all known producers by company name, address, and phone and the location of their sites by county and township-range designation. Table 2 lists operators in each county and the commodities they produce.

The new directory, DOGAMI Open-File Report O-87-3, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5528. The purchase price is $5. Orders under $50 require prepayment. □

REVIEWS OF BOOKS—OLD AND NEW

Rediscovered:

by Ralph S. Mason, former State Geologist

Some Little-Known Scenic Pleasure Places in the Cascade Range in Oregon, by Ira A. Williams. Corvallis, Oregon Bureau of Mines and Geology, The Mineral Resources of Oregon, v. 2, no. 1 (May 1916), 114 p. (Available only in or through libraries.)

Here is a book that is a delight to read, is informative, plentifully illustrated, nicely put together — and that failed almost completely in accomplishing its goal "to enter upon a campaign of active and substantial development of her scenic resources." The "her," of course, refers to the State of Oregon. That the project was undertaken seventy years ago is remarkable, that little more has been done since then is even more so.

In 1915, the author, accompanied by a packer, two riding horses, and three pack horses set out from Government Camp on the south side of Mount Hood and rode along the backbone of the Cascade Range southward to Mount Jefferson, and more especially, Jefferson Park, which nestles against its north side. The leisurely two-week trip was designed to promote interest in tourism to some of the State's volcanic attractions. This trip was followed by a second one to the Three Sisters Mountains even farther south in the Cascade Range. The latter trip started out by auto from Eugene and proceeded over increasingly challenging roads up the McKenzie River Valley. The final portion of this trip was made largely on foot, and in some places even on "all fours."

As one reads the accounts of these two trips, a firm impression is formed that even though the scenery was magnificent, only the hardiest traveler would dare to duplicate the adventure. On the road up to the Cascades from Eugene, for instance, mention is made of a half-mile stretch where the auto was able to travel in high gear! On one risky stretch of trail leading to Jefferson Park, the author comments: "A reasonable amount of caution, however, and the exercise of ordinary judgment reduces the element of danger to such a degree that anyone possessing these qualities in just normal quantity need not hesitate to pass over it." One wonders how many "tourists" were still tempted to make the trip after reading that description.

In sharp contrast to much of today's travel, the 1915 journeys were leisurely, with many side trips and stops to examine features of interest and to comment at some length on them. Many of the geologic features encountered are described in simple, nontechnical language. Even the highly technical petrographic procedure of examining thin sections of rock under a petrographic microscope is described as the party stops at an outcrop of what is now known as the Nimrod granite. Nongeologic phenomena such as flowers and forested areas are also described in considerable detail.

Scenic *Pleasure Places* is profusely illustrated with black and white photos, a few of which have been hand-tinted. Unfortunately the state of the art in photography and printing at that time resulted in less than top-quality prints, especially for some of the panoramic views, with distant snow-covered peaks blending invisibly with the sky. Some of the roadside pictures evoke a powerful nostalgia for things long past — the winding dirt road completely enclosed above by towering firs, the author's pony parked squarely in the single, rutted track, serenely aware that no other vehicle would come that way for a long time.

The author has produced an unusually lucid and error-free text, although the reviewer thought for a time that one glaring error had crept in: In several cases, both Bend and Tumalo are placed in Crook County, which actually lies many miles to the east of these two towns. A check in Loy's "Atlas of Oregon," however, reveals that at the time the author was preparing his text Crook County did in fact encompass both towns — and a lot more real estate to boot. Crook County was originally carved out of Wasco County in 1882 and then suffered the indignity of being itself quartered into what is now Jefferson County, Deschutes County, a greatly reduced Crook County, and the southern portion of Wheeler County. Sic transit gloria...

It is patently unfair for a reviewer to re-examine a work seventy years after the author finished with it. However, the author has produced a piece of writing that adroitly tackles a scientific subject and presents it as an adventure that can be enjoyed both vicariously and actively. This has prompted the reviewer to dust off the faded blue cover and take a second look inside.

For the snow-covered peaks are still there and every bit as beautiful as they were in 1915. Even more importantly, the area surrounding the peaks has been protected from development by the establishment of wildernesses. No roads come very close, and just as the author had to do seventy years ago, any hiker today must approach these beauty spots on foot or on horseback. And this is the way it should be. Natural processes are characteristically slow and deliberate. They yield their secrets only to those who will take the time to examine them in a leisurely fashion —just as the author did so long ago.

Just released:

Cataclysms on the Columbia: A Layman's Guide to the Features Produced by the Catastrophic Bretz Floods in the Pacific Northwest, by John Eliot Allen, Marjorie Burns, and Sam C. Sargent Timber Press, 1986, 210 p., hardcover $19.95. Available from local bookstores or the publisher, Timber Press, 9999 SW Wilshire, Portland, OR 97225 (add $3 for shipping and handling).

If you have ever driven along the Columbia River between Portland and The Dalles and noted such features as hanging waterfalls, steep cliffs with rounded hills above, horizontal sediment terraces between dipping beds of basalt, the scoured "scablands" of The Dalles, or large landslides along the Columbia, then you will appreciate John Allen's latest book, which explains the causes of many of these phenomena.

He and coauthors Marjorie Burns and Sam Sargent tell really two stories. One is the account of at least 40 floods that between 12,800 and 15,000 years ago swept from a temporary lake in Montana across the Columbia River drainage to the Pacific—changing thousands of square mile the of Oregon and Washington topography in the process. The other story is that of J Harlan Bretz, the tenaceous geologist who in the face of open hostility from many of his fellow geologists solved the riddle of "geological peculiarities" in eastern Washington by demonstrating that they had been caused by ancient floods, called in this book "the Bretz floods" in his honor.

The Bretz story is a classic example of the way a geologist turns observations of many details, some of which may appear to be unrelated, into a coherent explanation of a natural event. Anyone who has spent a hot summer's day on the Columbia Plateau has to be impressed by Bretz's ability to imagine the immense floods that repeatedly engulfed the area so long ago. The authors clearly understand the magnitude of Bretz's work and the floods he described and are able to convey the excitement and wonder of both in terms the layman can understand.

The accounts of both the Bretz story and the floods make for fascinating reading. Add to that numerous ground and oblique aerial photographs, detailed maps and descriptions of specific places, and self-guided tours of affected areas of Washington and Oregon, and you have a book that will be enjoyed by anyone who is interested in geology of the Pacific Northwest. This is the kind of book you will first read at home and then take out in the field with you, so you can see first hand the evidence of the Bretz floods. □

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that we feel are of general interest to our readers.

AN INVESTIGATION OF FLUID INCLUSIONS AND GEOCHEMISTRY OF ORE FORMATION IN THE CEDAR CREEK BRECCIA PIPE, NORTH SANTIAM MINING DISTRICT, OREGON, by Mark B. Winters (M.S., Western Washington University, 1985)

The Cedar Creek breccia pipe is located in the North Santiam Mining District, Oregon, approximately 50 km east of Salem. It was emplaced in the Sardine Formation, a series of andesitic flows, breccias, tuffs, and small intrusives of middle to late Miocene age.

The breccia pipe was discovered by Amoco Minerals Co. through soil sampling, a ground magnetic survey, and drilling. It is elliptical in plan view with maximum axes of approximately 110 and 145 m and extends vertically downward over 350 m. The contacts between the pipe and the surrounding country rock are sharp and characterized by sheeted fault zones. A quartz diorite intrusive is located directly beneath the pipe. It is porphyritic, weakly mineralized, and exhibits quartz-sericite alteration.

Two overlapping stages of hydrothermal mineralization are recognized. The first involved the alteration of breccia fragments to fine-grained quartz, sericite, chlorite, and carbonates. The second stage resulted in the deposition of quartz, sericite, chlorite, tourmaline, apatite, hematite, chalcopyrite, bornite, molybdenite, tetrahedrite, pyrite, galena, and sphalerite in open spaces. A later stage during which minor carbonate veins formed is also recognized. Siderite and kaolinite were deposited during this late stage.

Four types of fluid inclusions were distinguished and subjected to microthermometric analysis. Type-I inclusions consist of vapor and liquid and homogenized to liquid at temperatures of 150° to 500° C. The salinities of type I inclusions range from 0 to 23 equiv. wt. percent NaCl. Type-II inclusions consist of vapor, liquid, and halite. Homogenization temperatures of type-II inclusions range from 200° to greater than 625° C. Sixty-five type-II inclusions homogenized to liquid by vapor disappearance and have salinities of 31 to 39 equiv. wt. percent NaCl. Three homogenized to liquid by halite disappearance and have salinities of 58 to greater than 65 equiv. wt. percent NaCl. Type-III inclusions consist of vapor, liquid, halite, and sylvite. Twenty-four of 31 type-III inclusions that were analyzed homogenized to liquid by vapor disappearance, the remainder by halite disappearance. Homogenization temperatures of type-III inclusions range from 325° to greater than 625° C and salinities from 45 to 80 equiv. wt. percent NaCl + KCl. Type-IV inclusions consist of vapor, liquid, halite, sylvite, and one or more other solid phases. Two of these solid phases were tentatively identified as gypsum and anhydrite. Homogenization temperatures of type-IV inclusions range from 375° to 525° C. Thirty-two homogenized to liquid by vapor disappearance, 13 by halite disappearance.

Petrologic and fluid inclusion data indicate that three major hydrothermal events occurred. The first event is represented by type-III and -IV inclusions, the second by type-II inclusions, and the last by type-I inclusions.

Fluid inclusion leachates were analyzed by ion chromatograph. Na, K, Li, NH_4, Cl, SO_4, NO_3, and Br were separated. The Na/K and Na/Li ratios determined from the leachate analyses were used to calibrate Na/K and Na/Li geothermometers.

Data from fluid inclusion and petrologic studies were combined with available thermodynamic data to create a model for ore transportation and deposition processes. Copper and iron were carried in solution as CuCl and $FeCl^+$. Ore deposition occured at 250° to 350° C. A decrease in temperature is probably the primary cause of ore deposition, but an increase in pH and decrease in chloride concentration may also be important.

STRATIGRAPHY AND SEDIMENTOLOGY OF THE OLIGOCENE COLESTIN FORMATION, SISKIYOU PASS AREA, SOUTHERN OREGON, by Erick Anthony Bestland (M.S., University of Oregon, 1985)

The Oligocene Colestin Formation, situated at the base of the Western Cascade Group in southern Oregon, consists of nonmarine volcaniclastic and pyroclastic deposits and lava flows. The formation in its type area near the Oregon-California border has a maximum thickness of 1,600 m and is here divided into nine informal members. Each member consists predominantly of one of the following lithologic types: (1) volcaniclastic deposits of andesitic and basaltic composition, (2) rhyolitic pyroclastic and reworked pyroclastic deposits, or (3) basaltic and andesitic lava flows. The formation is largely contained within an east-west trending graben, which was down-faulted contemporaneous with deposition. Three members in the upper part of the Colestin Formation are characterized by distinct sequences of volcaniclastic alluvial-apron deposits. The alluvial aprons developed adjacent to volcanic centers that were situated to the east along the Oligocene Cascade arc.

VOLCANIC STRATIGRAPHY OF THE DESCHUTES FORMATION, GREEN RIDGE TO FLY CREEK, NORTH-CENTRAL OREGON, by Richard M. Conrey (M.S., Oregon State University, 1985)

About 225 lava flows and ash-flow tuffs of the Deschutes Formation (DF) were mapped at Green Ridge. The units fill east-trending paleovalleys which "sky-out" westward and dip east; the eastward dip of the units decreases as they are traced eastward. The source of the units was west of Green Ridge, as evidenced by the increase in the number of ash-flow tuffs and lava flows in the DF from east to west toward Green Ridge and the presence of viscous silicic lavas and lag deposits in ash-flow tuffs on the west flank of Green Ridge. The exposed DF section at Green Ridge is 1,400 ft thick and consists mainly of basaltic andesites with subordinate diktytaxitic basalts, andesites, dacites, aphyric basaltic andesites and andesites rich in Fe and Ti, ash-flow tuffs, and sediments. The upper 400 ft of the section is devoid of ash-flow tuffs and dacites. Nine paleomagnetic polarity intervals, five normal and four reversed, are recognized in the section; tentative correlation of these intervals with the magnetic time scale suggests that the oldest DF unit exposed at green Ridge is 6.5 m.y. old, and the youngest 4.4 m.y. old.

The DF units at the crest and west of Green Ridge are cut by at least five N.- to N. 13° W.-trending, down-to-the-west normal faults in a zone about 5 mi wide. These faults were possibly active as much as 5 m.y. ago; the developing faults may have provided structural pathways for the ascent of the mafic lavas in the upper 400 ft of the section. The faulting that created the Green Ridge escarpment was probably finished by 3 m.y. B.P. and perhaps earlier. The presence of dense, Fe- and Ti-rich lavas throughout the DF section implies that magmas had relatively easy access to the surface during DF time (7.6-4.4 m.y. B.P.), which suggests that the east-west extensional tectonism that culminated in the

(Continued on page 62, ***Abstracts)***

Glimpses of DOGAMI history

As it started operating in mid-1937 under the first director, Earl K. Nixon, the Oregon Department of Geology and Mineral Industries indeed worked up a storm. The first announcement in the first Press Bulletin *issued (see below) was a summary of the projects started immediately. Further witness of the number of plans and accomplishments through 1938 is the fact that during this period twice as many reports were published as on the average in subsequent years—in fact, about as many as DOGAMI usually publishes nowadays . . .*

From *Press Bulletin No. 1* (November 1, 1937)

"*Bureau Conducts Economic Investigations.* The State Department of Geology and Mineral Industries has caused a number of investigations to be started. Work is proceeding satisfactorily, and reports on progress will be made from time to time.

"A study of the refractory clays of Western Oregon and their geological relationships is in progress. Dr. Hewitt Wilson, Ceramic Engineer of the U.S. Bureau of Mines and Professor of Ceramics at the University of Washington, is in charge of the testing of the clays to determine their economic value and their possibilities of use in future developments in the lower Columbia River area. Ray C. Treasher, Geologist of the Department, is in charge of the geological portion of the work.

"A statewide report of quicksilver is being handled by Mr. C.N. Schuette, Consulting Engineer, who has had much experience in this field. . .

"The effect of placer mining on the Rogue River is being studied by Dr. Henry B. Ward, Ichthyologist, and by Mr. A.M. Swartley, Consulting Mining Engineer of this Department. . .Mr. Swartley will also be in charge of an investigation of the agricultural lime possibilities of the Willamette Valley.

"The occurrence of tungsten minerals in the Wallowa Mountain region has been partially investigated by Mr. W.O. Vanderberg of the Reno station of the U.S. Bureau of Mines, and the survey is being continued by the Department.

"Mr. Raymond Miller, Metallurgist for the U.S. Engineer Department, is preparing a report on the feasibility of electric steel furnace operation in the lower Columbia River area.

"Dr. Warren D. Smith, Head of the Department of Geography, University of Oregon, is preparing a report on the mineral resources of Lane County. The oil possibilities of the Clarno basin are being surveyed by Mr. D.K. Mackay, Mining Geologist of this Department. A state geologic map is in preparation, under the direction of Mr. Ray C. Treasher, assisted by the staff. Mr. A.M. Swartley, aided by the staff, is revising the catalogue of mines."

From the "Progress Report" in *Press Bulletin No. 2* (December 1, 1937)

"Prospecting for chromite in southern Oregon has been rather difficult. The area is covered with a heavy growth of vegetation which tends to conceal the outcrops, and the deposits themselves are usually quite pockety in nature. Dr. F.W. Lee, Geophysicist of the U.S. Survey, has been retained by the State Department of Geology and Mineral Industries to conduct some experiments with geophysical prospecting for chromite in southern Oregon. . .

"The situation in regard to manganese is considerably like that for chromite. The change in economic conditions makes it possible to consider seriously deposits which have not been economically workable in the past and which may now be of considerable importance. Mr. F.W. Libbey, Mining Engineer, is re-investigating the manganese areas in the light of modern market conditions. At present he is located at Medford and is working in the Lake Creek and Evans Creek district. . .

"Mr. Nixon, Director, has been in the field about half the time the past month, engaged in inspecting some dredge properties in eastern Oregon with the point of interesting qualified dredge operators; arranging for and starting the Clarno structural survey; interesting steel people in manganese operations; arranging for continued investigation of the Rogue River muddy-water situation; and making some field study of black sand concentrates and collecting samples for tests to suggest possible future use of this mineral product as a source of iron, titanium, and chrome."

From *Press Bulletin No. 3* (January 8, 1938)

"*Activities During First Half Year.* During the period from July 1st to December 25th, the Department received and issued somewhat over 5,000 letters covering general correspondence, publicity and publications, grubstakes, assaying and laboratory work, and requests for information. This is an average of thirty-five letters per day for 145 working days, exclusive of State Assay Laboratory correspondence.

"At the Grants Pass State Assay Laboratory, 611 samples were received, and 1,210 quantitative and 120 qualitative determinations were made. At Grants Pass, the assayer is occupied for approximately 55 percent of his time assaying, 25 percent meeting prospectors and answering inquiries, and the remainder writing assay reports and answering mailed inquiries.

"The Baker Assay office received 642 samples, made 1,262 assays, 40 wet determinations, and numerous qualitative tests. Visitors in quest of information numbered more than 500.

"The record shows that the Director has been in the field slightly more than half the time, visiting the more important mining districts and individual mines." □

***(Abstracts** continued from page 61)*

formation of the Green Ridge faults was present throughout deposition of the DF.

The major element chemistry of DF diktytaxitic basalts, basaltic andesites, and andesites appears to change regularly with TiO_2 content, as shown by decreasing CaO/FeO* (FeO* = total Fe expressed as FeO) with increasing TiO_2, and by decreasing Al_2O_3 with increasing TiO_2 at constant MgO content. The basalts and basaltic andesites with the lowest TiO_2 contents also have the lowest alkali contents. These chemical trends appear to be caused by plagioclase, with subordinate olivine fractionation, and are consistent with the fact that plagioclase and olivine are virtually the only phenocryst minerals in the mafic DF rocks. It is likely that the diktytaxitic basalt with the lowest TiO_2 content is a parental magma.

Fractionation may account for the chemical variations within the mafic rock groups considered separately, but the progression from basalt to andesite appears to be the result of mixing of silicic and mafic magmas. The chemistry of the rocks, especially the CaO/Al_2O_3 ratios, is consistent with such mixing, as is the petrography; opaque minerals are very late to crystallize in the basalts and basaltic andesites, and there is increasing evidence for magma mixing in the series basalt through andesite. Such evidence includes multiple plagioclase populations in the same rock, both of which are resorbed, and resorbed pyroxenes and amphiboles.

Three flows of plagioclase megacryst-bearing basaltic andesite occur near the top of the DF section. The plagioclase megacrysts are up to 5 cm in length, commonly contain apatite inclusions, and resemble the plagioclase in anorthosite bodies. Ilmenite megacrysts are also present. The megacrysts and the presence of highly plagioclase-fractionated aphyric lavas rich in Fe and Ti in the DF suggest that anorthosite bodies are present beneath the north-central Oregon Cascade Range.

Two xenoliths of partly melted cordierite-sillimanite-quartz granulite gneiss were found in a DF ash-flow tuff. The xenoliths demonstrate that granulite-grade metamorphism and at least local partial melting of the lower crust took place beneath the north-central Oregon Cascades. □

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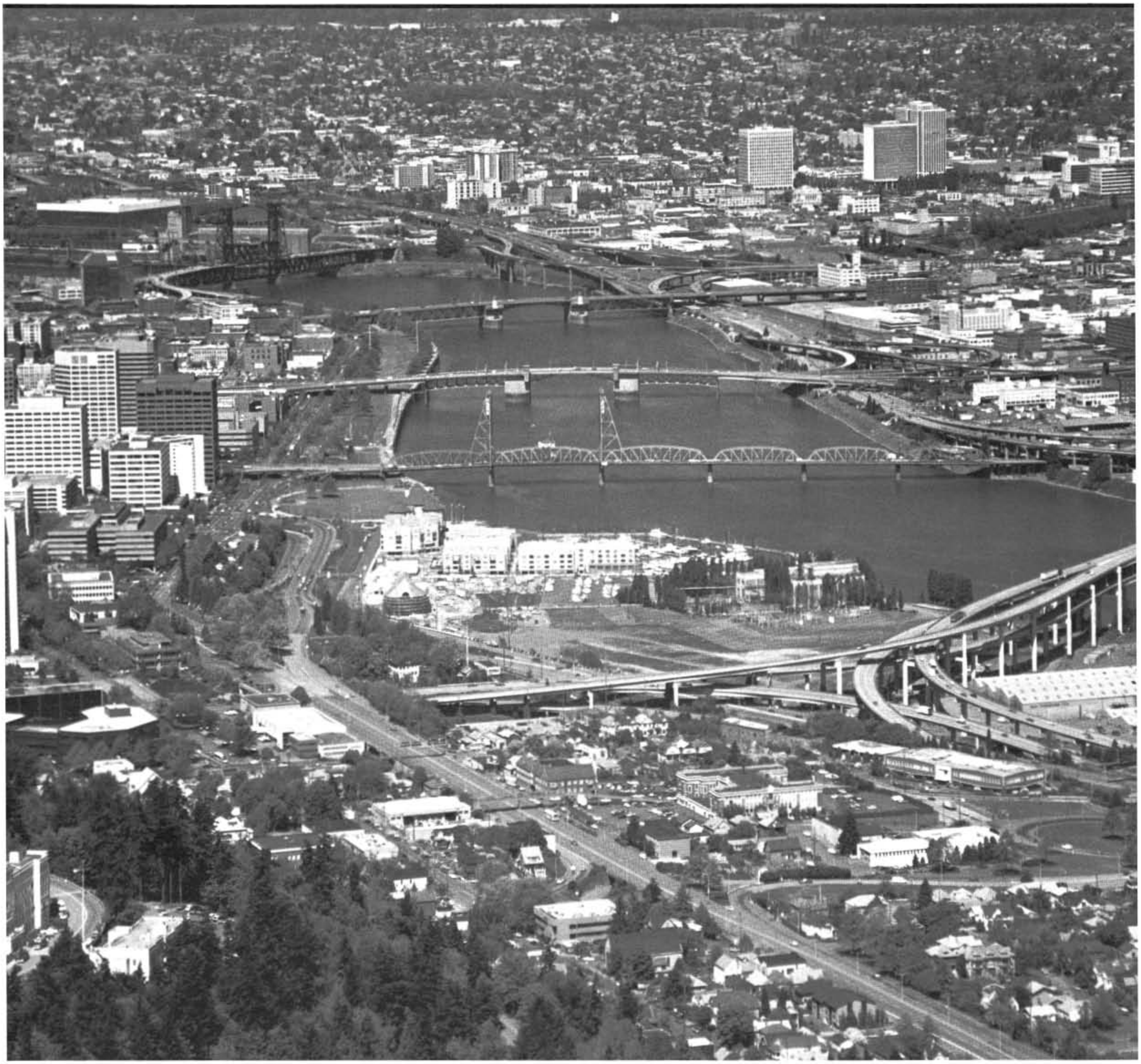

THIS MONTH:
Geothermal exploration in Oregon, 1986

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The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

View of Portland from the air. The Willamette River here flows in a generally northerly direction. A new book, *Portland's Changing Landscape,* which was recently published by the Portland State University Department of Geography, is discussed in an article on page 74. Photo courtesy of John V.A.F. Neal.

OIL AND GAS NEWS

Mist Gas Field production update

Cumulative gas production for 1987 at Mist Gas Field through April was 1,505,675 million cubic feet of gas. There are currently fourteen producing wells at the field, of which thirteen are operated by ARCO and one by Tenneco Oil Company.

Recent permits

Permit no.	Operator, well API number	Location	Status, proposed total depth (ft)
388	Leadco, Inc. CC-Jackson 22-17 36-009-00225	NW¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Application; 2,500.
389	Leadco, Inc. CC-Jackson 23-17 36-009-00226	SW¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Application; 2,500.
390	ARCO CFI 31-1-65 36-009-00227	NE¼ sec. 1 T. 6 N., R. 5 W. Columbia County	Application; 2,100.
391	ARCO Col. Co. 33-4-65 36-009-00228	SE¼ sec. 4 T. 6 N., R. 5 W. Columbia County	Application; 3,000.

□

Philip B. King, famed USGS geologist and author, dies

Philip B. King, of Los Altos, Calif., a world-renowned geologist and author, considered one of the preeminent scientists in the history of the U.S. Geological Survey (USGS), died Saturday, April 25, 1987, at the Mt. View Convalescent Hospital in Mt. View, Calif. He was 83.

King, a colorful as well as illustrious figure described as a giant in the field of geology, worked for the USGS for almost half a century. He is perhaps best recognized for the definitive geologic map of the United States, the currently used tectonic map of North America, and the geologic map of North America.

His books, *The Evolution of North America* (1950) and *The Tectonics of Middle North America* (1951), are reputed to be geologic classics and models of regional synthesis. Through his lifetime, Dr. King's books and reports were widely acclaimed for their lucid writing and his own superb illustrations. His total bibliography numbers more than 125 maps, reports, journal articles, and books. His works span a period of 55 years, beginning in 1926.

Up until his death he was working on reports, "pecking at the typewriter like a child," according to his family. He had completed 12 or 13 pages of a new paper on Paleozoic rocks before he died.

For his map work and earlier success in deciphering the geology of the Marathon Basin in Texas and the Great Smoky Mountains in Tennessee, King was awarded the Penrose Medal in 1965, the nation's highest geologic award. In the same year in Moscow, he was presented the Lomonosov medal, the highest equivalent honor bestowed by the Soviet Union.

King was a member of the National Research Council Committee on Tectonics, a Fellow of the Geological Society of America, and a Fellow of the American Association of Petroleum Geologists. Among other high honors, he was awarded the U.S. Department of Interior Distinguished Service Award. □

Geothermal exploration in Oregon, 1986

by George R. Priest and Neil M. Woller, Oregon Department of Geology and Mineral Industries; David D. Blackwell, Southern Methodist University; and Marshall W. Gannett, Oregon Water Resources Department

ABSTRACT

The general level of leasing activity was similar to last year's level. Drilling activity increased partly as a result of the U.S Department of Energy (USDOE) Cascade Deep Thermal Gradient Drilling Program, a cooperative effort between USDOE and industry. Drilling of intermediate-depth (1.2- to 1.5-km-deep) diamond core holes continued to be the dominant form of exploration in 1986. All drilling occurred either at Newberry volcano or in the High Cascades. Holes generally need to be relatively deep to be sure of penetrating the blanket of cold ground water that masks deep heat flow in these two areas. The most exciting news from the drilling programs is the discovery of temperatures of 107.1 °C at 405-m depth in California Energy's MZI-11A hole on the southeast flank of Mount Mazama (Crater Lake area). Other publicly available data from the Cascade and Newberry drilling programs indicate that, in most cases, the holes could have gotten reliable temperature-depth data at depths of as little as 0.65 km. Drilling through the cold water blanket or "rain curtain" may therefore be somewhat easier than previously thought.

Original permit requirements prompted California Energy Company to elect to suspend drilling on its MZI-11A hole. Possible alternatives to these requirements are being studied by the U.S. Bureau of Land Management (USBLM). Possible classification of the heat-flow anomalies in the floor of Crater Lake as "significant thermal features" by the federal government may have future regulatory impacts on geothermal development on Mount Mazama.

New age data from the U.S. Geological Survey (USGS) indicate that the silicic volcanic highland west of Bend may be much younger than previously thought. An average K-Ar age of about 0.3 million years (Ma) was obtained on an ash flow that was probably erupted from the highland. The 24-km-wide highland could therefore harbor still-hot magma bodies and associated hydrothermal systems.

Direct use of geothermal fluids continued to expand slowly in 1986, and more expansion is expected in 1987. Most of the activity is occurring at Klamath Falls, La Grande, Lakeview, and Vale. Oregon Trail Mushroom Company, a new $8.5-million fresh-pack operation, utilized the 107 °C water at Vale for heating. Klamath Falls expanded its district heating system. Use of geothermal heat for a greenhouse and for residential heating continued at Lakeview. New developments are planned at Olene Gap near Klamath Falls.

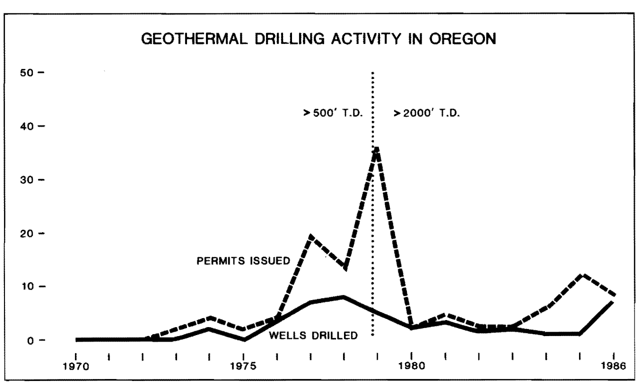

Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 610 m (2,000 ft).

LEVEL OF GEOTHERMAL EXPLORATION

Introduction

In 1986, geothermal-gradient drilling continued in the young volcanic rocks of the High Cascades and Newberry volcano. The amount of leased land declined on U.S. Bureau of Land Management (USBLM) land but increased on U.S. Forest Service (USFS) land. The total amount of federal land leased for geothermal resources has in general changed by only small amounts over the last two years. The trend toward deeper drilling and more stable leasing patterns is the natural result of industry moving into more advanced phases of exploration.

Drilling activity

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued in 1986. The number of permits decreased slightly, whereas the number of wells drilled increased. The increase in drilling was caused by two factors: (1) the need for companies to begin testing of leased lands in order to keep their leases and consolidate lease positions, and (2) the influx of U.S. Department of Energy (USDOE) matching funds for temperature-gradient drilling.

The USDOE program was focused on exploration of the High Cascades, Newberry volcano, and Medicine Lake volcano. This

Table 1. *Active permits for geothermal drilling in 1986*

Permit no.	Operator, well, API number	Location	Status, proposed total depth (m)
116	California Energy Co. MZI-11A 035-90014	SW¼ sec. 10 T. 31 S., R. 7½ E. Klamath County	Suspended; 413.
117	California Energy Co. MZII-1 035-90015	SE¼ sec. 13 T. 32 S., R. 6 E. Klamath County	Suspended; 148.
124	Thermal Power Co. CTGH-1 36-047-90002	SE¼ sec. 28 T. 8 S., R. 8 E. Marion County	Suspended; 1,463
125	Geo Operator Corp. N-2 36-017-90018	SW¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Suspended; 1,337.
126	Geo Operator Corp. N-3 36-017-90019	NE¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Suspended; 1,219.
127	California Energy Co. CE-NB-3 36-017-90020	NW¼ sec. 16 T. 22 S., R. 13 E. Deschutes County	Suspended; 1,325.
128	California Energy Co. CE-NB-1 36-017-90021	NW¼ sec. 16 T. 22 S., R. 12 E. Deschutes County	Permit issued; 1,219.
129	California Energy Co. CE-NB-4 36-017-90022	SE¼ sec. 4 T. 21 S., R. 12 E. Deschutes County	Suspended; 1,225.
130	Trendwest, Inc. Olene Gap 1 36-035-90016	NW¼ sec. 35 T. 39 S., R. 10 E. Klamath County	Permit issued; 914.

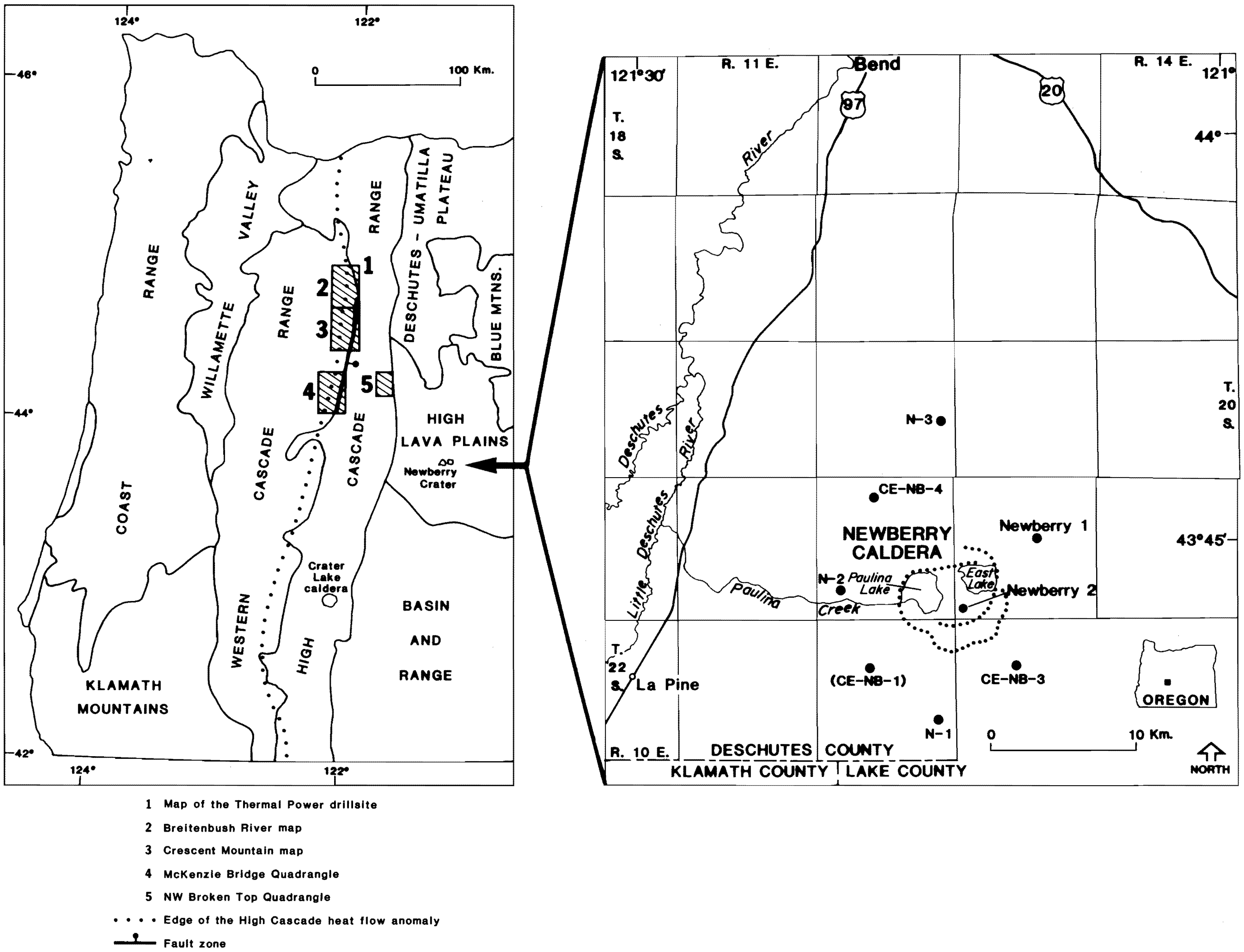

Figure 2. Physiographic provinces of western Oregon (after Dicken, 1950), showing areas of DOGAMI-supported geologic mapping and locations of recently drilled temperature-gradient holes. Also shown is the edge of the High Cascade heat-flow anomaly from Black and others (1983).

focus was partly responsible for the drilling activity in the High Cascades and at Newberry volcano. Temperature-gradient holes were drilled on the flanks of Mount Mazama (Crater Lake area), Newberry volcano (Paulina Lake area), and northwest of Mount Jefferson (Table 1; Figure 2).

Most holes were drilled by diamond coring, continuing a trend established in previous years. The diamond core technique allows the operators to drill through zones of lost circulation that are common in the highly fractured young volcanic rocks of the High Cascades.

The target depth of most of the temperature-gradient holes is about 1.2 km, although the hole drilled by Thermal Power Company northwest of Mount Jefferson was permitted to 1.52 km and drilled to 1.46 km (Table 1). No permits for prospect holes (holes less than 610 m) were issued (Figure 3). The prevailing perception of the industry is that drilling to a depth of about 1.2 km is necessary in order to guarantee that the holes will penetrate the so-called "rain curtain" effect that masks deep heat flow in the High Cascades and Newberry volcano. Temperature-gradient data from many of the holes suggest that drilling to somewhat shallower depths may effectively penetrate the "rain curtain" in most areas (see discussion of the temperature-gradient data below).

Leasing

The total leased acreage of federal lands decreased only about 4 percent in 1986 (Table 2; Figure 4). This slight decrease in leased lands was the result of a 58-percent decline in USBLM noncompetitive leases coupled with a 3-percent rise in USFS noncompetitive leases (Table 2). Overall, the amount of leased federal lands seems to have begun to stabilize, although the shift of land positions from the southeast Oregon USBLM lands to the Cascade lands of the USFS is continuing. A continuing slight decrease in leased lands is expected as companies explore and consolidate their land holdings. A major discovery in a new area could easily change this picture, however.

KGRA SALES

No Known Geothermal Resource Area (KGRA) lands were offered for bid in 1986.

DIRECT-USE PROJECTS

Direct use of geothermal fluids continued to expand slowly in 1986, and more expansion is expected in 1987. Most of the activity is occurring in the Klamath Falls area, La Grande, Lakeview, and Vale.

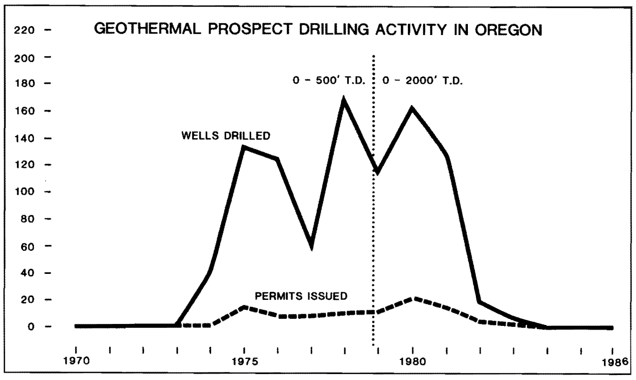

Figure 3. Geothermal prospect-well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth of less than 610 m (2,000 ft).

Oregon Trail Mushroom Company, a new $8.5-million fresh-pack operation, utilizes a 107 °C aquifer at Vale for heating and cooling. Geothermal heat is used to maintain a constant temperature for various processes in the 16,728-m^2 facility. The operation employs about 100 people and produces 2.3 million kg of mushrooms per year. Other users at Vale are Ag-Dryers (a grain-drying facility), Hawley Meat Packing (slaughterhouse heating and washing), and a greenhouse operation. More information on this area is given below in the section on activities of the Oregon Water Resources Department (OWRD).

Klamath Falls is pursuing expansion of its district heating project. Whereas the downtown loop is temporarily shut down because of pipe leakage, a new heating loop was added to heat local residences in the Michigan Street area (Kent Colahan, personal communication, 1987). Construction of the new loop was supported by a $600,000 grant from the U.S. Department of Housing and Urban Development. The same resource is used by the Oregon Institute of Technology (OIT) to heat the campus, although, unlike the City, which reinjects spent fluids, the OIT system discharges to the surface.

Olene Gap, a thermal area east of Klamath Falls, has been the focus of efforts by Trendwest Company to develop a geothermal industrial park. According to an article in the November 12, 1986, Klamath Falls *Herald and News*, Trendwest drilled a test hole to 183 m and encountered a 38,000-lpm aquifer at about 22 °C. The company intended to drill to about 760-910 m but became discouraged when the aquifer was encountered. Bob Kent of Trendwest Company was quoted as stating, "We hit upon a source of water that is so large, it might make it difficult to bring up [hot water] at that location." The article goes on to indicate that Trendwest has been contacted by aquaculture firms interested in utilizing the 22 °C aquifer to raise channel catfish. Exploration will reportedly continue in the area.

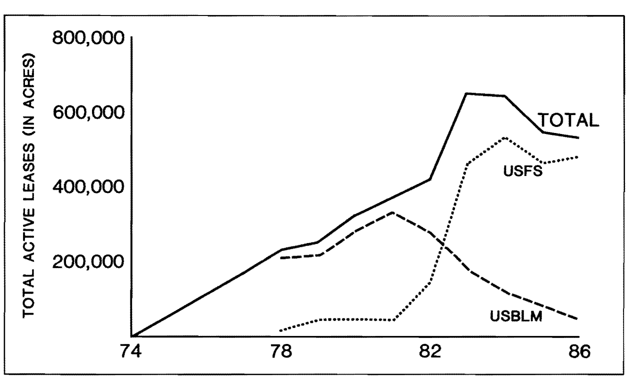

Figure 4. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December of 1986.

Table 2. *Geothermal leases in Oregon in 1986*

Types of leases	Numbers	Acres	
Federal active leases:			
Noncompetitive, USBLM	22	25,106	
Noncompetitive, USFS	256	475,361	
KGRA, USBLM	12	26,000	
KGRA, USFS	1	360	
Changes during 1986:			
Total 1-1-86	294	545,916	
Noncompetitive, USBLM	-19	-33,921	(-58%)
Noncompetitive, USFS	+14	+13,935	(+3%)
KGRA, USBLM	+3	+1,938	(+8%)
KGRA, USFS	-1	-1,040	(-74%)
Subtotal	-3	-19,088	(-4%)
Total 12-31-86	291	526,828	
Federal leases relinquished:			
Noncompetitive, USBLM	244	381,052	
Noncompetitive, USFS	78	175,708	
Competitive, USBLM	50	92,308	
Competitive, USFS	7	11,565	
Federal leases pending:			
Noncompetitive, USBLM	0	0	
Noncompetitive, USFS	110	No data	
State leases:			
Total active in 1986	No data	No data	
Applications pending in 1986	No data	No data	
Private leases:			
Total active in 1986	No data	No data	

No significant geothermal development has occurred recently in Lakeview. The binary cycle electrical generating station set up several years ago remains idle primarily due to economic considerations and low energy demand. Geothermal heat is used at Lakeview by the Greenhouse, a local company, to maintain optimum growing conditions. Geothermal heat is also used to heat residences in a local subdivision and for the municipal pool.

DOGAMI ACTIVITIES

Oregon Department of Geology and Mineral Industries (DOGAMI) geologists completed field mapping of the McKenzie Bridge 15-minute quadrangle during 1986. Belknap, Foley, Terwilliger, and several unnamed hot springs occur in the area, which encompasses the transition zone between the High Cascades and Western Cascades near South Sister (Figure 2). The map is still being compiled and will not be published until late in 1987 or early 1988.

Two geologic maps, each encompassing the area of a standard 15-minute quadrangle, are scheduled for publication in 1987. These maps cover the transition zone between the High Cascades and Western Cascades from about Breitenbush Hot Springs to just south of the junction of Highways 126 and 20 (Figure 2).

The geologic mapping, which was completed with USDOE support, was aimed at defining the geologic context of major hydrothermal systems in the Cascade Range. The maps delineate a major zone of faulting that starts near the elbow of the North Santiam River and continues south to headwaters of Horse Creek in the McKenzie Bridge quadrangle (Priest and others, 1987b; Black and others, 1987) (Figure 2). The Western Cascades are uplifted relative to the High Cascades at this faulted boundary (Taylor, 1980; Brown and others, 1980; Priest and others, 1982, 1983). Belknap Hot Springs and adjacent unnamed hot springs are on this fault zone (Brown and others, 1980). No major fault has been mapped through Breitenbush Hot Springs. Thermal fluids in the Breitenbush area probably ascend from southeast of the hot springs within a series of gently dipping quartz-bearing ash flows of the Breitenbush Tuff (Priest and others, 1987a,b).

The Department received a grant from USDOE to do a geologic study of the previously mentioned Thermal Power drill hole. Lithologic correlation between the drill core and adjacent areas will be accomplished by (1) geologic mapping of 39 km^2 around the site, and (2) analysis of core from the hole and cuttings from nearby drill holes. Terry Keith and Keith Bargar of the U.S. Geological Survey (USGS) will do complementary studies of the hydrothermal alteration. Temperature and heat-flow data will be analyzed by David D. Blackwell of Southern Methodist University. An open-file report that synthesizes the data in terms of a geothermal model for the Breitenbush-Olallie Butte area will eventually be published.

RELEVANT RESEARCH BY OSU

Edward M. Taylor of Oregon State University (OSU) aided DOGAMI staff in mapping the McKenzie Bridge quadrangle. Taylor has also completed a paper on the geology of the northwest quarter of the Broken Top quadrangle. The paper will be published later in 1987 as a DOGAMI special paper and will contain a folded geologic map at a scale of 1:24,000.

Brittain Hill, a doctoral candidate at OSU, is extending his work on the Quaternary ash flows in the Bend area (Hill, 1985). He has acquired new data that support venting of the ash flows from the highland of silicic volcanic rocks west of Bend. His dissertation will be a unique study of the characteristics of small-scale pyroclastic eruptions. The geothermal implications of his work and of research by the USGS in the same area are discussed below.

ACTIVITIES OF THE U OF O

Workers at the University of Oregon (U of O) completed magnetotelluric surveys at Newberry volcano and in the central Oregon Cascade Range. The results were reported at the 1986 American Geophysical Union conference in San Francisco (Urquhart and others, 1986; Rygh and others, 1986). The survey at Newberry found a pervasive conductor at a depth of about 1 km (Urquhart and others, 1986). The survey in the central Cascade Range found a pervasive midcrustal conductor under the High Cascades and evidence in support of a graben structure that affects both the High Cascades and adjacent Western Cascades (Rygh and others, 1986). This inferred graben appears to be the same structure that has been interpreted from gravity data and referred to as the "Cascade graben" by Couch and Foote (1983).

USGS ACTIVITIES

David Sherrod of the Menlo Park USGS office completed reconnaissance mapping in several areas of the Cascade Range. This work is being done in part to contribute to a project headed by James G. Smith of the USGS aimed at producing geologic maps of the entire Cascade Range in the United States. Compilation of a 1:500,000-scale map of the Oregon part of the range will be one of the map products. Currently completed but unpublished maps by Sherrod include the following:

1. Mount Hood area:
   a) High Rock 15-minute quadrangle.
   b) Mount Wilson 15-minute quadrangle.
   c) 1:50,000-scale composite map composed of the Flag Point, Fivemile Butte, Friend, and Wolf Run 7.5-minute sheets.
   d) Bonneville Dam 15-minute quadrangle.
   e) Part of the Hood River 15-minute quadrangle.
2. Breitenbush Hot Springs 15-minute quadrangle (coauthored with Richard Conrey).
3. West half of the Crescent 1° by 2° sheet (coauthored with Norman MacLeod).
4. West half of the Klamath Falls 1° by 2° sheet (coauthored with Norman MacLeod).

George W. Walker and coauthor Norman S. MacLeod have completed their several-year compilation geologic map of the state of Oregon (scale 1:500,000). Work is also underway on a map of the Salem 1° by 2° sheet.

These USGS maps are not yet available, although the mapping in the southern Cascade Range of Oregon is shown in Sherrod's dissertation (Sherrod, 1986). This thesis is a major contribution to the geology of the southern half of the High Cascades and adjacent parts of the Western Cascades. It contains a particularly informative discussion of uplift in the Western Cascades.

Terry E.C. Keith and Keith Bargar continued to pursue hydrothermal alteration studies of holes drilled under the USDOE cost-share program. This work is not complete as yet.

Andre M. Sarna-Wojcicki published a summary of tephra correlation studies that are relevant to the geothermal potential of the Cascades in the Three Sisters-Bend area (Sarna-Wojcicki and others, 1987). The geothermal implications of these data are discussed below.

ACTIVITIES OF OWRD

The Ground Water Division of the Oregon Water Resources Department (OWRD) has a Low-Temperature Geothermal Program consisting of two major parts. The first part is a state-wide network of thermal wells and springs where water levels, flow rates, temperatures, and some chemical parameters are measured with a frequency ranging from quarterly to biennially, depending on location. The main purposes for this activity are to monitor the condition of developed resources and to collect baseline data in undeveloped areas. Data collection is focused primarily in areas that have undergone development or that exhibit significant development potential. The observation network includes Klamath Falls, Vale, Lakeview, Olene Gap, the Western Cascade hot springs, the Harney Basin, and the Grande Ronde Valley. An additional area of activity is downtown Portland, where nonthermal water is heavily utilized for the purpose of heating and cooling office buildings.

The second major part of the program is aquifer characterization. This consists of intensive study of individual areas to determine the extent, thickness, hydraulic characteristics, and recharge and discharge rates of the known geothermal aquifers. These studies take at least two years to conduct and typically involve evaluation of geologic, geochemical, geophysical, and hydrologic aspects of the ground-water system. The ultimate purpose of such investigations is to determine as closely as possible the maximum sustainable production capacity of the system and to recommend some management scheme.

OWRD is currently studying the known geothermal area at Vale. To date, the Vale project has included quarterly monitoring of water levels, temperature/depth logging of all wells in the hot-well area (to determine total heat flux and discriminate individual aquifers) with regular, periodic relogging of key wells, geologic reconnaissance, and field checking of published geologic mapping. In addition, OWRD has conducted preliminary sampling and analysis of chloride in the Malheur River area to evaluate the feasibility of calculating the total geothermal discharge in the area through chloride flux measurements.

Future OWRD work includes stream-temperature studies, well-location surveys and leveling, analysis of drill cuttings from wells (if available), and pumping tests.

The area at Vale known to be underlain by hot aquifers at shallow depths is quite small, probably less than 40 acres. However, this flux of 107 °C water represents a significant amount of energy and is important to the local economy. There has been fairly rapid development of this resource in the last five years, including the construction of the previously mentioned mushroom growing plant, and additional development is planned.

The two other major low-temperature geothermal areas in

Oregon are Klamath Falls and Lakeview. The Klamath Falls geothermal system is the largest known and most highly developed low-temperature geothermal resource area in the state and is utilized for domestic, commercial, and institutional space and water heating, as well as for industrial applications. OWRD data indicate that water levels in the Klamath Falls geothermal reservoir have exhibited a modest decline of about 0.3 m per year for the last decade. Investigations by the City of Klamath Falls suggest that this loss in pressure is attributed to the withdrawal of geothermal water without reinjection, with peak withdrawals estimated at about 3,000 gallons per minute. In 1985, to mitigate this decline, the City of Klamath Falls adopted a Geothermal Management Act that requires reinjection of all geothermal effluent by 1990 (with special exceptions). A fairly major aquifer characterization project and extensive aquifer test were completed in 1984 by the USGS and Lawrence Berkeley Laboratories. OWRD has no active research ongoing in the area, and the agency's activities there are limited to semiannual water-level measurements in about 20 wells, tracking of development, evaluation of individual injection proposals (in cooperation with the Department of Environmental Quality), and participation on the local Geothermal Advisory Committee.

ACTIVITIES OF ODOE

In 1986, geothermal activities of the Oregon Department of Energy (ODOE) focused on research and support for other agencies. ODOE performed economic research into new geothermal power plants. This work was done cooperatively with the Washington State Energy Office for the Bonneville Power Administration (BPA). For another section of BPA, ODOE also provided information on specific steps to take toward geothermal resource confirmation. Direct-use research into district heating was expanded to include all energy sources. That work resulted in a published paper (Sifford, 1986) and another to be published by ODOE in 1987.

ODOE continues to respond to inquiries on geothermal energy development from the public. Over 100 such responses were provided in 1986. ODOE also certifies geothermal tax credits. Eighty residential and seven business tax credits were certified in 1986. ODOE continues to provide leadership in the Pacific Northwest Section of the Geothermal Resources Council (GRC). Finally, ODOE reviewed and commented on the geothermal energy aspects of several National Forest Draft Management Plans.

ACTIONS OF REGULATORY AGENCIES CONCERNING GEOTHERMAL EXPLORATION

California Energy Company stopped drilling on its MZI-11A hole on the southeast flank of Mount Mazama, because it could not meet the requirements stipulated in the Environmental Assessment (EA) for the Mount Mazama area that have been interpreted to prohibit drilling without circulation. California Energy Company contends that it is not technically feasible to maintain circulation in the hole, given the frequency of lost circulation zones in typical hydrothermal systems. The company requested two changes in stipulations to the EA: (1) that they be allowed to drill without circulation, and (2) that the maximum allowed depth of drilling be extended from 1.2 km to 1.7 km. All potential environmental effects of these proposed amendments to the EA are now being evaluated by USBLM. Edward Sammel (USGS, retired) and Sally Benson (Lawrence Berkeley Laboratory) are collaborating on a study of the ground-water flow system in the vicinity of Crater Lake and the potential effects of introducing drilling mud into this flow system. Sammel is a contractor to USBLM, whereas Benson's work is funded primarily through USDOE. Dennis Simontacchi of USBLM estimates that the environmental review will be complete by the end of April 1987. Proposed amendments will then be available for public comment for 30 days. It is conceivable that an amended EA could be finalized by early June 1987. There would then be a 30-day period for appeals.

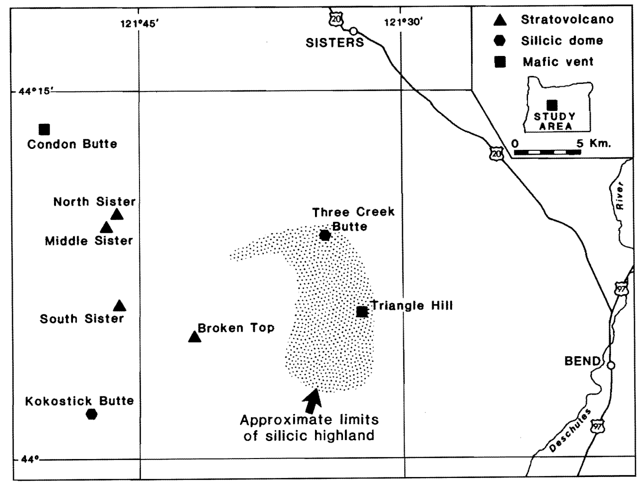

Figure 5. Index map showing the locations of the silicic highland west of Bend relative to various volcanic centers (taken from an unpublished 1987 figure by Brittain Hill, Oregon State University).

The USBLM, in response to an October 15, 1986, Act of Congress, suspended geothermal leasing on federal lands (see Section 115 (2)(a) of the October 15, 1986, *Congressional Record*). The act gave the Secretary of the Interior 120 days to publish a proposed list of "significant thermal features" in the National Park System. After publication of the proposed list, the Secretary was given 60 days to evaluate public comment and send the final list to the Committee on Energy and Natural Resources of the Senate and Committee on Interior and Insular Affairs of the House of Representatives. The proposed list was published on February 13, 1987; the final list is to be sent to Congress in the near future.

The proposed list contained references to the heat-flow anomalies found by the USGS on the floor of Crater Lake (Williams and Von Herzen, 1983). The Department of the Interior is now deciding whether these heat-flow anomalies qualify as "significant thermal features" under the guidelines of the Congressional act.

SILICIC HIGHLAND WEST OF BEND—NEW DATA ON THE GEOTHERMAL POTENTIAL

New isotopic age data on an ash-flow/air-fall eruptive sequence near Bend suggest that local pyroclastic rocks are much younger than previously supposed. Four new K-Ar analyses from the Tumalo tuff, a rhyodacite ash-flow tuff that crops out west of Bend, yielded an average weighted age of 0.29 ± 0.12 million years (Ma) (A.M. Sarna-Wojcicki and J.K. Nakata, unpublished data cited by Sarna-Wojcicki and others, 1987). Previous ages on this ash-flow and the cogenetic, compositionally identical Bend pumice ranged from 0.83 ± 1.5 Ma (recalculated from Armstrong and others, 1975, by Fiebelkorn and others, 1983) to 3.98 ± 1.9 m.y. (Fiebelkorn and others, 1983). The large analytical errors were the result of large amounts of atmospheric argon contamination in the samples. Reversely magnetized lava flows were thought to overlie the Tumalo tuff, leading previous workers to conclude that the Bend pumice and Tumalo tuff were older than about 0.9 Ma (Armstrong and others, 1975). However, Sarna-Wojcicki and others (1987) could not reproduce the reversed magnetization measurements.

The variation in grain size and distribution of the Tumalo tuff and Bend pumice suggest that they were probably erupted from a 24-km-wide highland of silicic lavas (Taylor, 1978) immediately west of Bend and east of the Three Sisters (Figure 5) (Hill, 1985). Three Creek Butte, one of the silicic domes on the eastern margin of this highland (Figure 5), has rhyodacite lava (74 percent SiO_2) so similar in composition to these two tuff units that it is probably from the same magma chamber (Hughes, 1983; Brittain Hill, in preparation).

Mimura and MacLeod (1978) and Mimura (1984) studied imbrication in the Tumalo Tuff and concluded that the ash flow had a source southwest of the Bend area and about 32 km south of the silicic highland. Hill (1985) pointed out that the data from this study are also consistent with a source on the silicic highland, provided the ash flow traveled in drainage systems similar to the present ones. The current drainage system would cause ash flows to flow northeast, giving an apparent southwesterly source, even for ash flows erupting from the east (Hill, 1985).

Silicic magmas generally reside at relatively shallow levels in the crust and are associated with much of the world's best geothermal resources (Smith and Shaw, 1973, 1975). Smith and Shaw (1973, 1975) suggest that not more than about 10 percent of a silicic magma chamber is erupted during one pyroclastic eruption. The size of the Bend pumice-Tumalo tuff eruption is thought to be greater than 10 km^3 (Hill, in preparation), so a silicic magma chamber greater than 90 km^3 probably existed under the silicic highland about 300,000 years ago. Significant magma chambers and geothermal systems appear to be present in silicic volcanic centers with similar or greater age. Examples are Yellowstone Park, Long Valley caldera, and Valles caldera. Therefore it is likely that similar chambers and geothermal systems still exist under the silicic highland.

ENCOURAGING TEMPERATURES AT MOUNT MAZAMA—NEW TEMPERATURE-DEPTH DATA FROM THE USDOE-INDUSTRY DRILLING PROGRAM

USDOE has sponsored geothermal assessment projects in and adjacent to the Cascade Range for the last 10 years. Efforts by the agency to provide reliable temperature-depth and heat-flow data in the High Cascades were generally defeated by the previously mentioned "rain curtain" effect. In 1985, the USDOE Division of Geothermal and Hydropower Technologies initiated the Cascade Deep Thermal Gradient Drilling Program aimed at penetrating the "rain curtain" by cost-sharing drill holes with industry. Temperature-depth curves for four of these drill holes are shown in Figure 6.

The MZI-11A hole, drilled by California Energy on the southeast flank of Mount Mazama, has an anomalously high temperature of 107.1 °C at a depth of only 405 m (Joseph La Fleur, written communication, 1987). The lowest 20 m of the hole had a gradient of about 372 °C/km, well above regional background gradients (Figure 6). Such high temperatures and gradients are evidence that the heat flow at this site has been raised above background by magmatic intrusion and/or upward convection of thermal fluids. This is very encouraging for the geothermal resource potential of the Mount Mazama area.

Three of the holes in Figure 6 have temperature gradients of 74-83 °C/km in the lower, relatively linear part of the curves. These values are typical of areas with normal background heat flow in the regional heat flow high associated with the High Cascades (e.g., see Black and others, 1983; Blackwell and others, 1978). Two of these holes have temperature-depth curves with isothermal zones bounded by gradients that are nearly horizontal (Figure 6). Curves with this shape are generally produced by movement of fluid that disturbs the normal conductive temperature gradient. Fluids in aquifers encountered by the borehole can move laterally across the hole or vertically within the hole. In the latter case, two scenarios are possible: (1) cool aquifers can sink into warmer fluid in the hole, lowering temperatures to the value of the cool aquifer, or (2) fluid from warm aquifers can rise, raising temperatures to the value of the warm aquifer. In each case the part of the hole disturbed by intra-borehole circulation will be nearly perfectly isothermal. The temperature-depth curve at intermediate depths in Geo Operator N-1 looks like case 1, whereas the curve at similar depths in Geo Operator N-3 looks like case 2. If the aquifers in each hole were cased off, the temperature gradients in both would probably be relatively linear below depths of about 400-500 m. Above those depths, the so-called

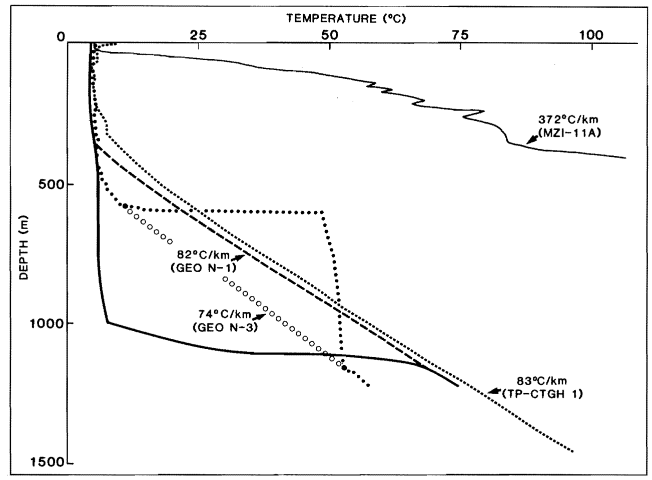

Figure 6. Temperature-depth curves of holes from the USDOE Cascade Deep Thermal Gradient Drilling Program. Dashed lines show the temperature-depth curves as they would be were they not affected by inferred intra-borehole fluid circulation. Inferred temperature gradients are shown in degrees Centigrade per kilometer. Temperature data in hole MZI-11A were taken only 20 hours after circulation of drilling fluids, so hole temperatures had probably not completely stabilized. Temperatures for MZI-11A were measured by Al Waibel of Columbia Geoscience; other measurements are by David D. Blackwell of Southern Methodist University. See Table 1 and Figure 2 for drill-hole locations.

"rain curtain" effect disturbs the heat flow, producing erratic, low temperatures in both Geo Operator N-1 and Geo Operator N-3 (Figure 6). In a hole such as Thermal Power CTGH1, where no significant aquifers were encountered at depth (Joseph Iovenitti, personal communication, 1986), a relatively linear gradient occurs below the shallow (300-m depth) flows of cold ground water. These observations suggest that the "rain curtain" at all of these drill sites extends only to depths of about 300-500 m. Valid temperature gradients could therefore have been found by drilling to only about 650 m. Whether these conclusions can be widely applied to other parts of the Cascades cannot be determined until the geologic and hydrologic context of each hole is studied in more detail.

ACKNOWLEDGMENTS

This paper could not have been written without the cooperation of numerous individuals in government and industry. The writers are indebted to Brittain Hill of OSU for sharing his unpublished research on the Quaternary volcanic stratigraphy in the Bend area. David Sherrod of the USGS provided a detailed summary of his many mapping projects. Dennis Simontacchi and Jack Feuer of USBLM shared their information on regulatory issues. Jacki Clark of USBLM provided the federal leasing data. Dennis Olmstead and Dan Wermiel of DOGAMI provided the data on drilling permits. Local residents and city officials at Vale, Lakeview, and Klamath Falls provided current information concerning direct-use projects.

The USDOE Cascade Deep Thermal Gradient Drilling Program is responsible for putting invaluable data in the public domain. The temperature and the lithologic information from the program have greatly increased our understanding of both the geology and geothermal resource potential of Newberry volcano and the High Cascades. Michael Wright of the University of Utah Research Institute helped coordinate the release of the temperatures and other data from the program. Joseph La Fleur of California Energy Company sent copies of his temperature data on hole MZI-11A for public release.

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Bob Bates re-opens Pandora's Bauxite

Bob Bates, Professor Emeritus of Geology at Ohio State University and author of "The Geologic Column" in *Geotimes*, is the author of *Pandora's Bauxite — The Best of Bates: Selections from the Geologic Column, 1966-1985*, recently published by the American Geological Institute (AGI). Bates has had much to say over the years about the "use and abuse of the language" — particularly when it comes to geology, and this book contains some of his choicest columns. As Bates says:

"My purpose ... has been to choose material that will be of interest and amusement to nongeologists as well as to specialists in the various fields of earth science. The items range in length from a line or two to a page or two; people with a short attention span should feel at home. Those who consider the geological sciences sacred and immune to humor will be happier reading the IUGS classification of igneous rocks or the Stratigraphic Code."

However, if you are interested in such subjects as "The Pterasaur of Ptexas"; "Melanopyxilation" (the study of black boxes); "Wor-dbreaks: bluep-rint for mans-laughter"; "Fiscal obfuscation"; "The unauthorized glossary of geology"; "Abandon *hopefully*, all ye who enter here"; "At the Lulu mine" (a lulu is a three-word expression with an adjective, two nouns, and no hyphens, producing such results as "unexploded bomb expert," "buried pipeline designer," "edible oil refinery," or "waterlogged wood experts"); "Obtaining the unobtanium;" or "The boola-boola concept," you find that this book is a joy to read.

Bates tells about the California dam protected by "heavy riffraff" and the Hari Krishna temple in West Virginia with water faucets made of "an opalescent pink marble called rose quartz." He reveals little-known facts such as the 1881 oil test in Franklin, Pennsylvania, that inadvertently drilled into the underground storage tanks of a brewery, making it the nation's first beer well. When a mine near one of the Great Lakes sprang a leak and water with large numbers of fish entered the mine, Bates explains that the mine workings intersected a "perched water table."

Bates loves puns. For example, a "sinter" is a position played by the tallest person on a southern basketball team, "forsterite" is said of a graduate student grinding out his thesis, or a "harpolith" is a rock with ripple marx. He coins new mineral names such as

*(Continued on page 74, **Pandora's Bauxite**)*

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that we feel are of general interest to our readers.

THE GEOLOGY AND GEOCHEMISTRY OF THIRTEEN CINDER CONES AT CRATER LAKE NATIONAL PARK, OREGON, by Elizabeth M. Prueher (M.S., University of Oregon, 1985)

Major- and trace-element variations exhibit an increase in excluded elements and a decrease in included elements as differentiation increases, indicative of crystal fractionation of olivine, clinopyroxene, orthopyroxene, and plagioclase.

LREE patterns for the rocks are irregular. First, basalt is enriched in LREE relative to other members of the suite. Second, there is a repeated pattern of three pairs of basalt and andesite, with each successive basalt enriched in LREE relative to the preceding andesite. From consideration of the REE data, it is apparent that the cinder cones were derived from more than one partial melt.

Compositional variations in the magmas of the cinder cones support the conclusion that they were generated by more than one partial melting event. Partial melting of a mantle source region with the composition of peridotite could have produced primitive basaltic magmas. Subsequent mixing and fractional crystallization produced the more differentiated basaltic to andesitic magmas.

BIOSTRATIGRAPHY OF THE COWLITZ FORMATION IN THE UPPER NEHALEM RIVER BASIN, NORTHWEST OREGON, by Neil B. Shaw (M.S., Portland State University, 1986)

Examination of stream and roadcut exposures of the Cowlitz Formation allows the selection of measured representative sections and collection of fossils from an area roughly defined by the intersection of the boundaries of Clatsop, Columbia, Tillamook, and Washington Counties in Oregon. The study defines the features of the local environment of deposition, correlates sections to derive a composite columnar section, and develops a checklist of species for both microfossils and megafossils of the Cowlitz Formation.

A composite columnar section of 720 m based on three stream sections and one roadcut section is presented. Twenty-two selected samples yielded fossil assemblages that included a total of forty-seven species of foraminifera, twenty-seven species of macrofossils, and a small number of terrestrial plant fossils and trace fossils.

Paleoecologically diagnostic species and assemblages indicate that the features of the environment of deposition varied. Water depth varied from upper bathyal or outer neritic in the lower Cowlitz Formation to possibly inner neritic during deposition of the upper Cowlitz sands. Cool bottom temperatures and probably warm, stratified surface waters are also indicated.

The integration of paleontological and sedimentary structural evidence has resulted in several models proposed for the environment of deposition of the Cowlitz Formation. A comparison of these models is made.

The composite section is assigned to the Narizian foraminiferal stage of Mallory. Only one zone, the *Plectofrondicularia* P. *jenkinsi* zone of Rau, is recognized. It is represented by two faunules, the *Plectofrondicularia-Lenticulina* (lower) faunule and the *Cibicides-Lenticulina* (upper) faunule. A narrow overlap of the teilzones of *Cyclammina pacifica* Beck and *Lenticulina texanus* (Cushman and Applin) permits local correlation.

One measured section, the Sunset Camp section, was continued across the Cowlitz-Keasey contact in order to achieve stratigraphic control. The Narizian-Refugian stage boundary appears to be coincident with this contact in this section. The fossils recovered from the Keasey Formation above the Cowlitz-Keasey contact were assigned to the *Sigmorphina schenki* Zone of Rau. This contact is gradational and poorly defined. A marked reduction in mica characterizes Keasey rocks as well as the disappearance of the foraminiferal species *Cibicides natlandi* Beck, the occurrence of which is considered here to be diagnostic for the Cowlitz Formation.

The Cowlitz Formation in the study area can be correlated with the type Cowlitz Formation in southwest Washington; the Spencer Formation, Yamhill, the Nestucca and the Coaledo Formations of Oregon; the McIntosh Formation of Washington; and the Tejon Formation of California. □

Geographers write book about Portland

Approximately 2,600 geographers from all over the country assembled in Portland this April for the 83rd Annual Meeting of the Association of American Geographers. As part of the event, the local hosts, the Portland State University (PSU) Department of Geography, prepared and published a collection of essays on different aspects of Portland. Entitled *Portland's Changing Landscape* and edited by Larry W. Price of the PSU Geography Department, this book contains 13 essays by various authors from PSU, other universities, and the community.

This 220-page book begins appropriately enough with a chapter by Price on Portland's landscape, which is of course determined by the local geology. Price describes the geologic units found in the Portland area, including basalt of the Columbia River Basalt Group, Troutdale Formation, Boring Lava, and the Portland Hills Silt. He discusses the Missoula floods that inundated the Portland area several times about 13,000 years ago. Price notes that "...Portland has been the scene of what are among the largest lava and water floods on the face of the earth."

Succeeding chapters are concerned with other aspects of Portland, such as climate and weather, the riverscape, downtown Portland, neighborhoods, shaping and managing Portland's metropolitan development, transportation, economy, the Port of Portland, the Silicon Forest, and livability. Geologists will note how many of these subjects are influenced by local geology.

Change is the theme of many of the essays—whether it be change in geology, topography, the character of the city and rivers, or human activities. By bringing in a historical perspective and then examining the current status of these various aspects of Portland, the authors are able to present the city in a multidimensional way, "summing up, taking stock of where we have been and where we are going."

Portland's Changing Landscape is available at selected local bookstores. It may also be purchased directly from the Department of Geography, Portland State University, Portland, OR 97207, phone (503) 229-3916. The purchase price is $11.95. □

(Pandora's Bauxite, *continued from page 73)*

the Central America copper mineral guatemalachite, the gangue mineral umbilicalcordierite found only in the mother lode, or the Turkish semiprecious stone constantinopal.

This 88-page book is not available in the Oregon Department of Geology and Mineral Industries library. A personally owned copy is floating around the Department but will be hard to find. Copies may be purchased, however, for $7.95 from AGI, 4220 King Street, Alexandria, VA 22302. Orders must be prepaid. □

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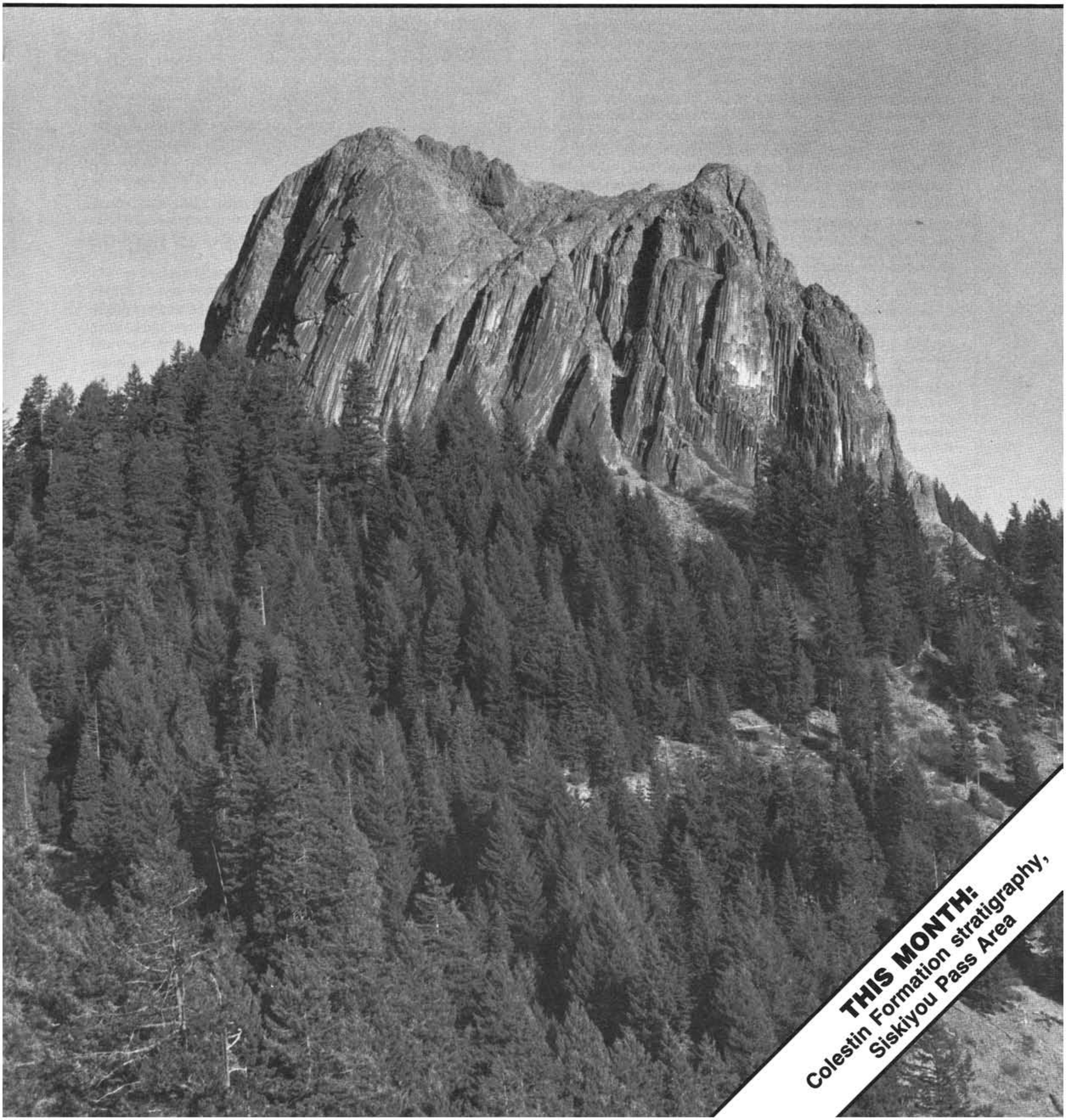

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The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Pilot Rock, seen here from the south, is a Tertiary hornblende andesite plug located in the Siskiyou Pass area. See related article beginning on next page.

OIL AND GAS NEWS

Drilling planned for July

Further exploration in the Mist Gas Field is likely to begin this month. ARCO Oil and Gas Co. has 18 permits in effect in the field and plans to start drilling activities in midsummer. The permits are in T. 5 N., R. 4 W.; T. 6 N., R. 4 W.; and T. 6 N., R. 5 W., and range in proposed total depth from 2,000 to 4,850 ft.

In addition, Leadco, Inc., formerly Leavitt's Exploration and Drilling Co., plans to drill its locations in sec. 17, T. 5 N., R. 4 W., this summer. The proposed depth for both of these locations is 2,500 ft.

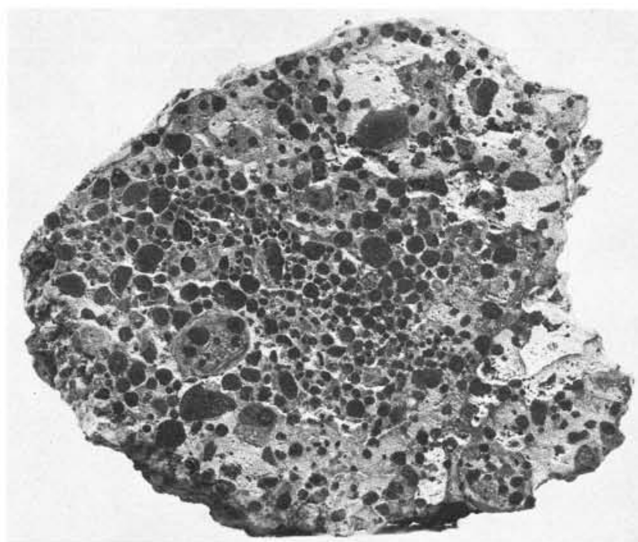
Mountain States Petroleum to file for permits

Mountain States Petroleum of Roswell, N. Mex., plans to submit applications to drill for locations in Douglas County and possibly in Coos County. As part of the drilling program, the company may reenter the Hutchins & Marrs well Great Discovery 2 in sec. 20, T. 30 S., R. 9 W. The work is planned for this drilling season. □

Glimpses of DOGAMI history — bauxite discoveries made

Sizeable deposits of ferruginous (iron-bearing) bauxite (aluminum ore) were discovered in 1944 in Washington County, north and west of Portland, by geologists of the Oregon Department of Geology and Mineral Industries (DOGAMI). Following this initial discovery, other large deposits of aluminum ore were found in Columbia and Washington Counties.

Publication of these studies by DOGAMI in the late 1940's and early 1950's resulted in large-scale exploration and evaluation projects by Alcoa, Aluminum Company of Canada, and Reynolds Metals Company.



The specimen shown above is typical of the pisolitic (made up of pealike grains) variety of bauxite that is commonly found in the deposits in Washington and Columbia Counties. The dark-brown pisoliths usually contain more than 40 percent iron and are imbedded in a lighter colored matrix that consists largely of limonite (goethite) and gibbsite. □

Volcanic stratigraphy of the Oligocene Colestin Formation in the Siskiyou Pass area of southern Oregon

By Erick A. Bestland, Department of Geology, University of Oregon, Eugene, OR 97403

ABSTRACT

The Oligocene Colestin Formation, situated at the base of the Tertiary volcanic sequence in the Western Cascades in southern Oregon, consists of nonmarine volcaniclastic and pyroclastic deposits and lava flows. In its type area near the Oregon-California border, the formation is broken down into nine informal members that have a combined maximum thickness of approximately 1,600 m. Each member is characterized by one of the following lithologic types: (1) coarse volcaniclastic deposits of andesitic and basaltic composition, (2) rhyolitic pyroclastic and reworked pyroclastic deposits, and (3) basaltic and andesitic lava flows.

The upper boundary of the Colestin Formation is mapped at a stratigraphically higher position than that mapped by Wells (1956). The lithostratigraphic units added to the Colestin Formation are consistent with Wells' (1956) definition that the formation is dominantly volcaniclastic.

In the lower part of the formation, the members are contained within an east-west-trending graben. The graben is bounded to the north by the Siskiyou Summit fault and to the south by less well-defined east-west faults located in the Oregon-California border area. During deposition of the Colestin's upper members, the graben continued to subside on the north, but at the graben's southern boundary, subsidence slowed, and volcanic material overflowed and obscured the graben faults. Prior to graben faulting and deposition of Colestin detritus, the area south of the Siskiyou Summit fault was uplifted. This uplift produced the northward-dipping paleoslope and southward thinning of the underlying upper Eocene Payne Cliffs formation. Later graben subsidence along the Siskiyou Summit fault juxtaposed the Payne Cliffs formation and the Colestin Formation.

Deposition of the volcaniclastic and pyroclastic debris within the graben occurred in an alluvial apron-type setting. The aprons developed adjacent to volcanic centers situated to the east along the Oligocene Cascade arc. Periodically, lava flows inundated the alluvial surface, but more commonly, volcanic material was deposited by laharic debris flows, stream floods, and pyroclastic flows.

A distinctive type of coarse-grained volcaniclastic deposit, termed "hyperconcentrated flood flow deposits" (Smith, 1986), is common in the Colestin Formation. These deposits consist of discontinuous, horizontally bedded, very poorly sorted, pebbly conglomerates and granular sandstones that are clast supported. In the Colestin Formation, these deposits commonly grade upward from matrix-supported debris-flow deposits (lahars).

INTRODUCTION

The Western Cascade Range of southern Oregon and northern California consists of deeply eroded andesitic and basaltic stratovolcanoes and shield volcanoes, rhyolitic pyroclastic deposits, related intrusive rocks, and epiclastically reworked material derived from these primary volcanic products. The volcanic strata of the Tertiary volcanic sequence of the Western Cascades range in age from latest Eocene/early Oligocene to late Miocene. The initiation of Cascade volcanism has been dated at 35-40 million years (Ma) from rocks of the Western Cascades (Smith and others, 1980; Fiebelkorn and others, 1983) and from rocks at the base of the John Day Formation in central Oregon (Swanson and Robinson, 1968; Robinson and others, 1984).

This paper describes the stratigraphy and depositional history of volcanic epiclastic, pyroclastic, and lava-flow lithostratigraphic units situated at the base of the Western Cascade Tertiary volcanic sequence in southern Oregon (Figure 1). Nine informal members belonging to the Oligocene Colestin Formation in its type area (Wells, 1956) have been mapped over an area of about 100 km². These members have a combined maximum thickness of approximately 1,600 m. The area of detailed study stretches along the Western Cascade Range for 15 km from the Oregon-California border to 4 km north of Siskiyou Pass (Figure 2). This paper deals almost exclusively with the Colestin Formation in its type area.

The base of the Tertiary volcanic sequence of the Western Cascades is well exposed in the Siskiyou Pass area, owing to 1,000 m of relief in the Tertiary units and relatively sparse vegetation. The lower members of the Colestin Formation are exposed along streams draining the Siskiyou Mountains, and the upper members are well exposed in natural outcrops and in roadcuts along Interstate 5 and Highway 99, which transect the upper part of the formation in the Siskiyou Pass area.

The Tertiary and Cretaceous rocks in this area form a northeastward-dipping homocline with dips ranging from 35° in the Cretaceous Hornbrook Formation to 8° in the Oligocene Roxy For-

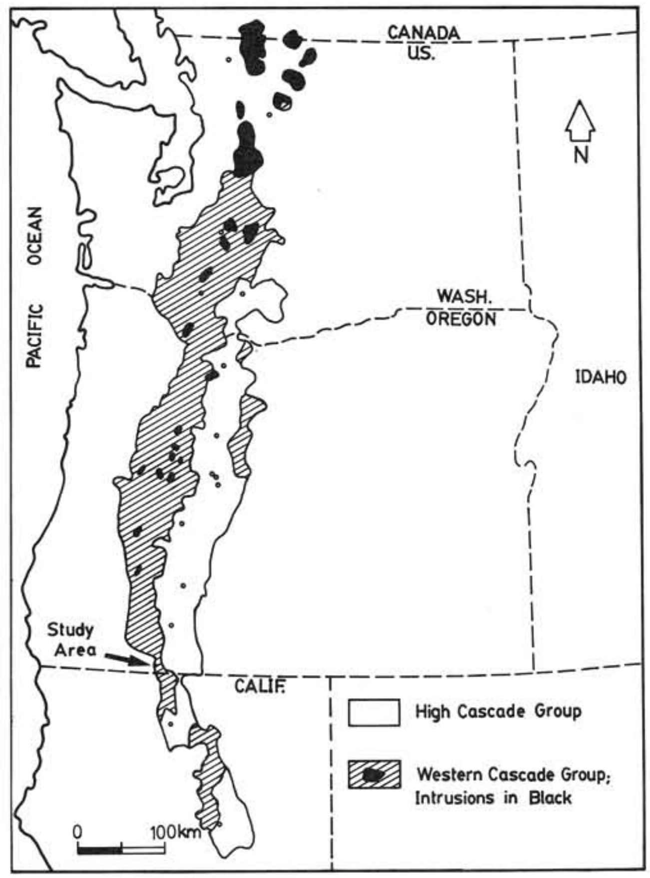


Figure 1. Geologic map of the Cascade Range showing the study-area location and the distribution of Western and High Cascade rocks (modified from Hammond, 1979). Open circles are major andesite-dacite volcanic centers.

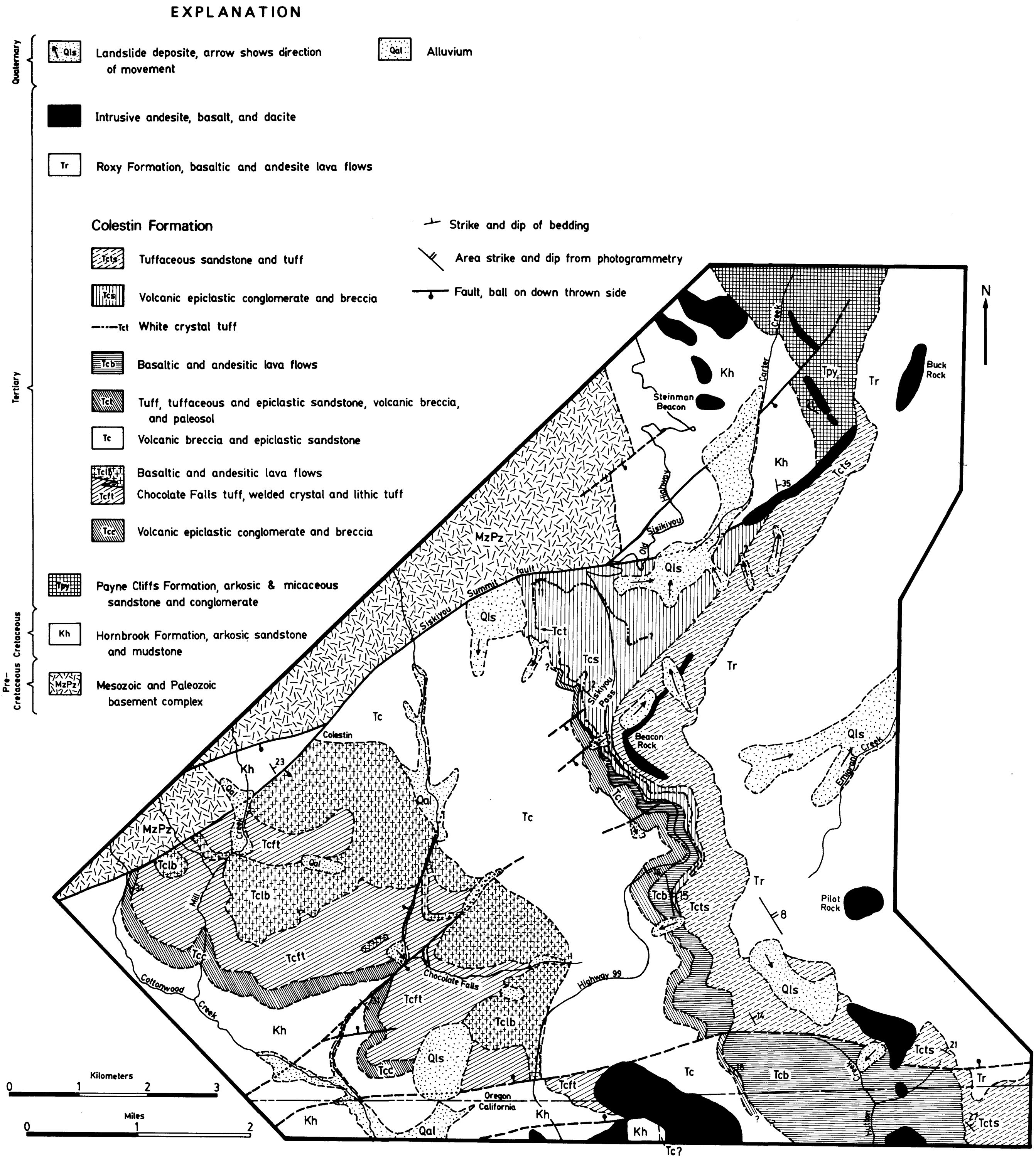


Figure 2. Geologic map of the Colestin-Siskiyou Summit area.

mation. In general, dips decrease to the east, away from the Klamath Mountains Province. Numerous high-angle faults offset the Tertiary and Cretaceous rocks and trend northeast, east-west, and northwest. The Siskiyou Summit fault is a major fault that trends northeast-southwest, offsets the outcrop pattern of Cretaceous and Tertiary rocks by as much as 15 km, and brings the Colestin Formation in contact with basement rocks of the Klamath Mountains Province.

The Colestin Formation was initially mapped and defined by Wells (1956) for sequences of volcaniclastic and pyroclastic rocks that crop out in scattered locations at the base of the Western Cascade Tertiary volcanic sequence in the Medford quadrangle. Wells (1956) designated an area near the town of Colestin along the California-Oregon border as the type area of the Colestin Formation. Lava flows overlying these volcaniclastic rocks were assigned to the Little Butte Volcanic Series, the base of which is represented in the Ashland-Medford area by the Oligocene Roxy Formation (Wells, 1956). The base of the Little Butte Volcanic Series was defined by Wells (1956) as the stratigraphically first 100-ft-thick lava flow in the Tertiary volcanic rocks of the Western Cascades. Peck and others (1964) used Wells' (1956) Colestin and Little Butte divisions of the Tertiary volcanic rocks and mapped them to the north of the Medford quadrangle in the central Oregon Cascades.

Carlton (1972) completed a petrographic and stratigraphic study of the Colestin Formation in the Siskiyou Pass-Colestin area and also studied the formation to the south in northern California. Carlton (1972) followed Wells' (1956) Little Butte/Colestin boundary but apparently did not map any lithologic units in the Colestin Formation.

LITHOSTRATIGRAPHIC UNITS OF THE COLESTIN FORMATION

In its type area, the Colestin Formation can be divided into nine informal members that consist predominantly of one of the following lithologic types: (1) volcaniclastic conglomerates and sandstones with clasts of andesitic and basaltic composition, (2) rhyolitic tuffaceous sandstones and tuffs, and (3) basaltic and andesitic lava flow sequences. These members pinch out and interfinger with each other and are largely contained in a northeast-southwest-trending graben (Figure 3). The graben is bounded to the north by the Siskiyou Summit fault and is more diffusely bounded to the south by a series of east-west faults in the Oregon-California border area. Syndepositional graben faulting may have been widespread during deposition of the Colestin Formation and could explain the general thickening of most members toward the Siskiyou Summit fault.

Member Tcc

A basal fluvial conglomerate tens of meters in thickness rests with angular discordance on the Hornbrook Formation in most of the study area. The unit is poorly consolidated and poorly sorted and contains cobbles and boulders of andesitic and basaltic lava flow fragments (volcanic epiclasts of Fisher, 1966) and minor amounts of quartzite and argillite cobbles. Overlying the basal conglomerate is a ledge-forming, matrix-supported volcanic breccia unit (lahar) that is up to 20 m thick. The laharic unit contains altered and unaltered cobbles and boulders of basalt and andesite in a matrix of coarse sand. To the south, this member pinches out, and the overlying member Tcft rests on the Cretaceous Hornbrook Formation.

Member Tcft

A pyroclastic flow sequence up to 250 m thick is here informally referred to as the tuff of Chocolate Falls for exposures along Chocolate Falls Creek. The base of the tuff of Chocolate Falls consists of a lithic-rich pumice lapilli tuff. The bulk of the tuff of Chocolate Falls consists of tan crystal and pumice tuff with abundant white medium-grained plagioclase crystals and yellow pumice lapilli that are slightly elongated parallel to bedding. Most of the tuff is welded to varying degrees, and some parts display vapor phase alteration and devitrification textures. A dark-gray vitrophyre is locally present in the stratigraphic middle of the tuff sequence. This vitrophyre has an obsidianlike appearance where it is well developed.

Member Tclb

The lower basaltic member consists of basaltic and andesitic lava flows and can be divided into two parts (Figure 3). The lower sequence is interbedded with the upper part of the tuff of Chocolate Falls, and the upper sequence overlies the tuff. These lava flow units cap most of the ridges and form dip slopes in the upper Cottonwood Valley area. The lavas consist predominantly of plagioclase and pyroxene-phyric basaltic andesites.

Member Tc

Member Tc is an undifferentiated sequence of poorly consolidated volcanic debris flows, andesitic flow breccia, weathered volcanic siltstone, and volcaniclastic sandstone. The unit crops out very poorly and in some roadcuts resembles Quaternary colluvium or landslide debris.

Member Tcl

Member Tcl is a heterogeneous collection of lithologic units that are well exposed in Interstate 5 and Highway 99 roadcuts along the south side of Siskiyou Pass. The base of the member is defined by a white pumice lapilli tuff that forms white, ashy-looking outcrops where it is poorly welded and tan flaggy outcrops where it is welded (Figure 4). The tuff contains fine-grained brown biotite and a small amount of carbonized plant debris and has a slightly eutaxitic foliation.

Above the pumice lapilli tuff is a 10-m-thick sequence of tuffaceous sandstones and siltstones (Figure 5). Upward in this sequence of sandstones, the amount of tuffaceous material gradually decreases in favor of lava flow fragments. The tuffaceous sandstones grade upward into a 40-m-thick sequence of massive to crudely bedded brown sandstones composed of volcanic epiclastic debris (lava flow

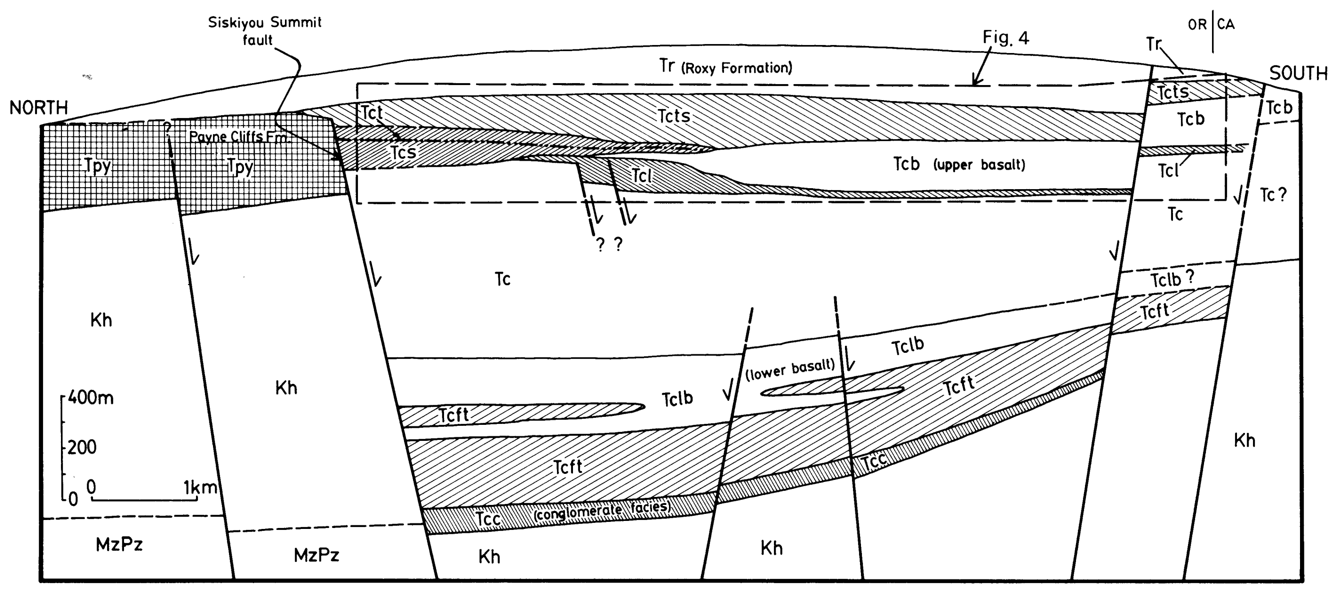


Figure 3. Composite cross section along strike of the Colestin Formation and Payne Cliffs formation. The area of Figure 4 is outlined with dashed lines.

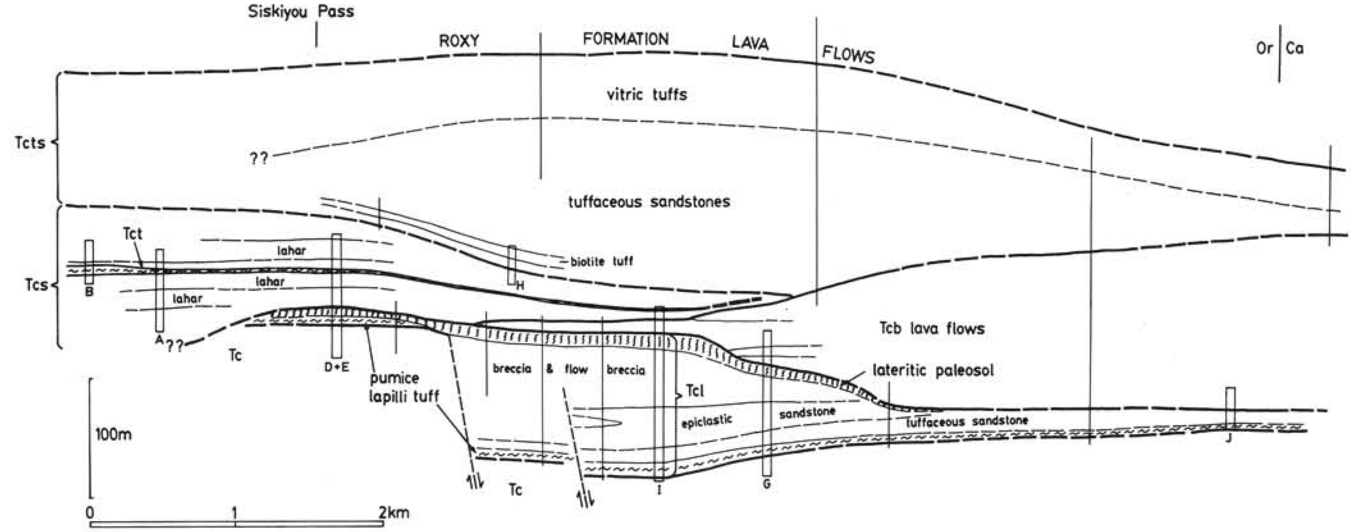


Figure 4. Stratigraphy of informal members Tcl, Tcb, Tcs, and Tcts in the upper part of the Colestin Formation between Siskiyou Pass and the Oregon-California border. Lettered rectangles are detailed measured sections, and vertical lines are well-exposed sections that were measured approximately (from Bestland, 1985b).

fragments). In the Interstate 5 roadcuts, this unit contains numerous dark-colored strips and spots, with the strips being on the order of 1-3 m long and 10-30 cm wide. Many of the strips and spots form halos around carbonized branches. Petrographic examination reveals that the dark coloration is due to pervasive chlorite cement.

Overlying the massive sandstones is a unit of unconsolidated andesitic boulder breccia that is up to 50 m thick. Scattered throughout this unit is andesitic flow breccia. Capping the boulder breccia is a weathered horizon that is locally up to 10 m thick. The weathered origin for this clayey siltstone is indicated by a gradation in clast alteration from largely unaltered clasts in the underlying breccia to a saprolite and up into a red clayey siltstone with well-developed ped structures and root traces. A chemical analysis (atomic absorption) of a red bricklike horizon in the paleosol (Figure 6) gave a composition of 26 percent Fe_2O_3, 47 percent SiO_2, and 9.5 percent Al_2O_3.

Member Tcb

Basaltic and andesitic lava flows of member Tcb rest on the paleosol of member Tcl and pinch out to the north between members Tcl and Tcs (Figure 4). A 30-Ma age of a lava flow in this member was determined by Sutter (1978). The unit forms dip slopes and scattered cliffy outcrops. Member Tcb thickens abruptly to the south, whereas member Tcl thins abruptly to the south. Paleosols, consisting of red and white silty claystone with well-developed ped structures, overlie the altered tops of lava flows in member Tcb along Highway 99, 2 km south of Siskiyou Pass. Near the California-Oregon border, member Tcb is approximately 200 m thick.

Member Tcs

Member Tcs, which consists of volcanic epiclastic sandstones, conglomerates, and lahars of andesitic and basaltic composition, is well exposed in roadcuts on Interstate 5 and Highway 99 along Siskiyou Pass. Channelized conglomerates and sandstones are common in this unit. Channel orientations and rare cobble imbrication in these deposits indicate a paleocurrent direction to the southwest. To the south of Siskiyou Pass and paralleling Highway 99, member Tcs pinches out between members Tcb and Tcts.

Many of the matrix-supported boulder and cobble lahar units grade upward into clast-supported, discontinuously bedded, pebbly conglomerates and granular sandstones (Figures 7, 8, and 9). The bedding in these conglomerates is produced by size variation and grading of the sand and gravel. These types of bedded, clast-supported conglomerates are termed "hyperconcentrated flood flow deposits" by Smith (1986) and are thought to represent a type of flow that is intermediate between the en-masse flow of laharic debris flows and normal fluvial flow.

Member Tct

A distinctive white crystal tuff is sandwiched between the darker colored volcaniclastic sandstones and conglomerates of member Tcs. This unit was mapped separately as member Tct (Figure 10). The tuff has a maximum thickness of 10 m in the northern part of its outcrop area and thins abruptly to the south. Lapilli-sized carbonized plant fragments are abundant and are generally aligned subparallel to bedding, as are the numerous plagioclase and quartz crystals. Petrographic examination of the vitric matrix of the tuff indicates that the glass shards are weakly welded and almost completely altered to zeolites (heulandite and clinoptilolite). Scanning electron microscope examination of the carbonized plant material reveals it to be composed of charcoalized wood fragments. Charcoal is in-

Figure 5. Roadcut along Highway 99, 2½ mi south of Siskiyou Pass, exposing the pumice lapilli tuff that marks the base of informal member Tcl. The pumice tuff is cut by a channel containing coarse, well-cemented tuffaceous sandstone. Hammer (see arrow) is just under the channel-pumice tuff contact.

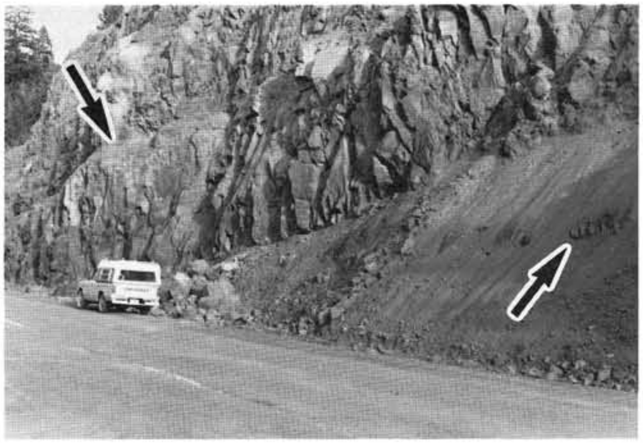


Figure 6. Roadcut along Highway 99, 2 mi south of Siskiyou Pass, exposing contact between the paleosol at the top of informal member Tcl and lava flows of informal member Tcb. Arrow on right side points to bricklike ferruginous horizon in paleosol; arrow on left side points to red paleosol interbed between lava flows.

dicated by fused and distorted cell walls and results from incomplete burning at a minimum temperature of around 290 °C (Cope and Chaloner, 1980).

Member Tcts

This member consists of approximately 250 m of tuffaceous sandstones, siltstones, and intercalated vitric and pumiceous tuffs. The unit as a whole is light colored and, compared to other Colestin units, is finer grained and less well exposed. The white vitric tuff and the underlying tuffaceous sandstones of member Tcts are tentatively correlated with Vance's (1984) Soda Springs member (J. Vance, personal communication, 1984), which Vance (1984) dated at 27 Ma.

A stratigraphic sequence consisting of lacustrine tuffaceous claystones, organic-rich layers with tuffaceous claystones, and welded pumice lapilli ignimbrite is exposed along Beacon Rock. The light-pink pumice lapilli tuff has a well-defined eutaxitic foliation and abundant biotite, feldspar, and quartz crystals in a welded vitric groundmass.

Capping the sequence of tuffaceous sandstones is a distinctive

Figure 7. Roadcut along Highway 99, half a mile north of Siskiyou Pass, exposing an indistinctly planar bedded granular sandstone-pebbly conglomerate sequence (informal member Tcs) that grades down into the matrix-supported volcanic breccia shown in Figure 9. Arrow points to the coarse-grained basal layer of the light-colored unit that is the white crystal tuff (informal member Tct). Outcrop is approximately 10 m thick.

Figure 8. Closeup of poorly sorted, granular sandstones (informal member Tcs) of Figure 7 that are interpreted as hyperconcentrated flood flow deposits.

white vitric tuff. The most widespread tuff has a brilliant white color and contains sparse plagioclase crystals and pumice lapilli in an unwelded vitric groundmass. Associated with this tuff is a light-gray welded and locally lithophysal tuff containing sparse, altered feldspar crystals. The gray tuff represents a welded part of the capping white tuff.

The capping white vitric tuff can be traced throughout the map area. It overlies the Siskiyou Summit fault on the west side of Buck Rock with no apparent offset. This relationship demonstrates that movement of the Siskiyou Summit fault, at least in this area, ended before deposition of this tuff.

PAYNE CLIFFS FORMATION

A discussion of the Colestin Formation is not complete without mention of the closely related Payne Cliffs formation (informally named by McKnight, 1971, 1984). North of the Siskiyou Summit fault in the Ashland-Medford area, the upper Eocene Payne Cliffs formation of McKnight (1971, 1984) lies at the base of the Teritary sequence; south of the fault, however, the Colestin Formation lies at the base of the Tertiary section. The outcrop extent of the Payne Cliffs formation thins to the south and ends at the Siskiyou Summit fault (Figure 2). The stratigraphic relations between the Payne Cliffs formation and the Colestin Formation are not well understood. The upper volcaniclastic part of the Payne Cliffs formation may be coeval with some part of the Colestin Formation; however, the exact correlation is not known.

Figure 9. Closeup of matrix-supported volcanic breccia (lahar; informal member Tcs) that grades up into the granular sandstones of Figure 8.

The formation consists predominantly of arkosic and micaceous sandstones and conglomerates with quartzite, argillite, metamorphic, and granitic clasts. The upper part of the formation is dominated by volcaniclastic material. McKnight (1971, 1984) has identified a gradation from arkosic and micaceous sandstones and conglomerates in the lower part of the Payne Cliffs formation to volcaniclastic and tuffaceous sandstones, conglomerates, and siltstones in the upper part of the formation. The volcaniclastic deposits at the very top of the formation examined in this study can be grouped into those with and those without muscovite. The Colestin Formation does not contain muscovite in any quantity. Abundant muscovite in Payne Cliffs volcaniclastic material indicates that north of the Siskiyou Summit fault, Cascade material was mixed with Klamath Mountain detritus. The volcaniclastic deposits without muscovite are very similar in composition, color, grain size, and sorting to many of the sandstones in the Colestin Formation. However, none of the members recognized in the Colestin Formation were identified in the upper volcaniclastic part of the Payne Cliffs formation.

The arkosic sandstones and conglomerates were deposited by a northward-flowing braided river system (McKnight, 1971, 1984). During deposition of the Payne Cliffs formation, an uplifted source area was present to the south in the Klamath Mountains (McKnight, 1971, 1984). A southern source area is indicated from the northward-dipping paleoslope and northward thickening of the formation (McKnight, 1971, 1984). The problem is: What happened to the formation in the Siskiyou Summit area? One interpretation is that the Payne Cliffs formation was deposited in the Siskiyou Summit area, which was subsequently uplifted, causing the formation to be eroded. This interpretation fits with the thinning of the Payne Cliffs formation to the south, which could have resulted from beveling of the formation during uplift. During deposition of the Colestin Formation, however, the area south of the Siskiyou Summit fault was downfaulted, thereby containing Colestin detritus. Therefore, a reversal of movement is indicated for the Siskiyou Pass area, with uplift occurring during the deposition of the Payne Cliffs formation and downfaulting occurring during Colestin deposition.

COLESTIN-ROXY FORMATION BOUNDARY

The Roxy Formation in the study area consists predominantly of dark-colored, dense plagioclase-phyric pyroxene basalts and andesites and only minor amounts of volcaniclastic and pyroclastic deposits. These lava flows cap ridges and form prominent dip slopes around Pilot Rock. Many landslides originate at the contact between the tuffs of member Tcts and the overlying basalts. Area strike and dip measurements using photogrammetric techniques (Ray, 1960) indicate that a slight angular discordance exists, at least locally, between these lava flows and the underlying Colestin Formation units (Figure 2).

Figure 10. Roadcut along the east side of Siskiyou Summit on Interstate 5, exposing a channel cut into volcanic conglomerates and breccia of informal member Tcs that is filled by the white crystal tuff (informal member Tct). Arrow points to carbonized plant debris in informal member Tct.

The boundary between the Colestin and Roxy Formations by the author (Bestland, 1985a,b) and in this report differs from the boundary mapped by Wells (1956), Carlton (1972), and Smith and Page (1977). The boundary between the Little Butte Volcanic Series and the Colestin Formation was defined by Wells (1956) as being the stratigraphically first 100-ft-thick lava flow. In the Siskiyou Pass area, the boundary between the Colestin Formation and the Little Butte Volcanic Series is recognized in this study to be at the contact of the white tuffs of member Tcts and the prominent cliff-forming basaltic lava flows designated as Roxy Formation. Volcanic strata previously assigned to the basal Roxy Formation by Wells (1956) consist chiefly of volcaniclastic and pyroclastic rocks. The lithology of these rocks is consistent with Wells' (1956) original designation that the Colestin Formation consists predominantly of volcaniclastic and pyroclastic deposits.

Wells' (1956) Colestin-Little Butte Volcanic Series boundary was mapped by previous workers at the base of member Tcb. The stratigraphic findings of this study demonstrate that the lava flows of member Tcb pinch out to the north between volcaniclastic deposits of Colestin members Tcl and Tcs (Figure 4). In the area of this pinch-out, previous workers have mapped a fault between the lava flows of member Tcb and the volcaniclastic rocks of members Tcl and Tcs (Elliott, 1971; Carlton 1972; Smith and Page, 1977; Smith and others, 1982). A thick paleosol horizon can be traced across the pinch-out of member Tcb. Syndepositional faults are located in the vicinity of the pinch-out of member Tcb. These faults cut member Tcl but do not noticeably offset the overlying members Tcs and Tct (Figure 4).

Future work on the lower parts of the Tertiary volcanic sequence in northern California may reveal that members Tcb, Tcs, and Tcts are of formational extent. Additional mapping to the south of the California border is needed to substantiate this suggestion and would hinge on whether the pronounced disconformity, represented by the strongly ferruginized paleosol, can be traced to the south.

DISCUSSION

Volcanic apron facies

The depositional environment of the Colestin Formation was interpreted on the basis of detailed stratigraphic and sedimentological work on the upper part of the formation (Bestland and Boggs, 1985). This work has resolved many of the lateral stratigraphic problems in a north-south direction (Figure 4). Unfortunately, proximal-distal facies relationships are not obvious because the source area for the Colestin deposits was located to the east of the formation's north-south outcrop pattern. Volcaniclastic deposits and facies models studied by other workers can be compared to the sedimentary structures and textures and the stratigraphic relationships of the Colestin deposits.

Volcaniclastic facies models that relate the relative distance from a volcanic center(s) have been made by Swanson (1966), Parsons (1969), Smedes and Prostka (1972), and Vessell and Davies (1981). The term "volcaniclastic apron facies" was developed from these studies and refers to volcaniclastic deposits that encircle, or partially encircle, volcanic centers of the stratovolcano type. The apron facies is analogous to an alluvial fan facies in coarseness of deposits and proximity to source area.

The lithology and sedimentary characteristics of the members in the upper part of the Colestin Formation compare well to the medial volcaniclastic facies of Vessell and Davies (1981) and to the coarse alluvial facies of Smedes and Prostka (1972). Distinctive characteristics recognized in the upper Colestin deposits that are indicative of apron facies aside from the coarseness, poor sorting, and high angularity of the clasts include well-developed channels, scarcity of fine-grained deposits, and lateral facies variations that delineate distinctive sequences composing the apron. Numerous large channels are present and are commonly filled with poorly sorted to unsorted conglomerate and sandstone. The channels lack lateral channel migration structures, and some appear to have been cut and filled during the same flood event.

Depositional reconstruction of the upper Colestin Formation

Members Tcl, Tcs, and Tcts represent three volcanic sequences of the apron that were developed adjacent to volcanic centers situated to the east along the Oligocene Cascade arc (Figure 11). Member Tcl accumulated in a small graben that was orientated roughly east-west. Syndepositional graben faulting complicated the stratigraphy and produced a local, but thick, accumulation of volcanic sandstones and breccia. After the small graben was filled, a prolonged period of nondeposition (volcanic quiescence) and weathering followed, producing the paleosol that caps member Tcl.

Effusive basaltic and andesitic volcanism followed the volcanic hiatus. These lava flows of member Tcb lap onto member Tcl to the north and thicken considerably to the southeast. Member Tcb lavas can be interpreted as valley fill or as the flank of a shield volcano. Because member Tcb thickens dramatically to the south and is onlapped to the north by member Tcs, member Tcb is interpreted as the flank of a shield volcano.

Weathering and soil formation on the upper surface of member Tcb was followed by andesitic volcanism of member Tcs. This volcanism produced the andesitic debris contained in the lahars and pebbly sandstones of member Tcs. The volcanic center that produced member Tcs was located to the northeast of the map area (Figure 11). This interpretation is indicated by the thickening of member Tcs to the north, the lapping of member Tcs onto member Tcb, and the southwest-northeast channel orientations in this unit.

Member Tcts represents a large alluvial apron that consists almost totally of rhyolitic pyroclastic debris of both ignimbrite and waterlain origin. The unit consists of sand-sized material and is distinctly finer grained than other Colestin deposits. The grain size could represent a more distal source compared to other Colestin units, but the sediment size probably reflects the grain size of the original pyroclastic material. The pyroclastic volcanism of member Tcts ended abruptly and was followed by effusive basaltic volcanism of the Roxy Formation lava flows.

SUMMARY AND CONCLUSIONS

Each lithostratigraphic unit of the Colestin Formation records a distinct episode of volcanism both in the composition of the volcanic products and in the mode of volcaniclastic deposition. Andesitic and basaltic volcanism generated largely effusive volcanic products, which, in turn, were the source material for boulder and cobble debris flows and pebbly hyperconcentrated flood flows. Rhyolitic pyroclastic volcanism produced easily erodible material that was deposited on the alluvial aprons by sandy stream floods and pyroclastic flows.

The rapid lateral facies changes that are ubiquitous in the Colestin Formation developed from deposition around active volcanoes. The lobelike depositional pattern of the members reflects the episodic nature of volcanic eruptions and the shifting of activity between volcanoes along the arc. Rapid erosion of erupted material from steep flanks of volcanoes produced rapid deposition on the alluvial apron. Between periods of deposition, the alluvial apron was eroded and weathered. Another factor that further complicated the stratigraphic interpretation was the syndepositional faulting that occurred during the aggradation of the apron. All of these factors produced a complex local stratigraphy that was worked out by field tracing of marker units (pyroclastic flows, lava flow sequences, and paleosols) and mapping of lithologic units.

All of the members, except member Tcl, are compositionally uniform. They are either rhyolitic tuffs and tuffaceous sediments or basalt-basaltic andesite lava flows and/or lahars. The observation that the members are either rhyolitic or basaltic and andesitic agrees with Lowenstern's (1986) geochemical data, which give a roughly bimodal chemical distribution for the Colestin lava flows and tuffs.

The syndepositional east-west faulting in the Colestin Formation may be widespread in the Western Cascades of southern Oregon.

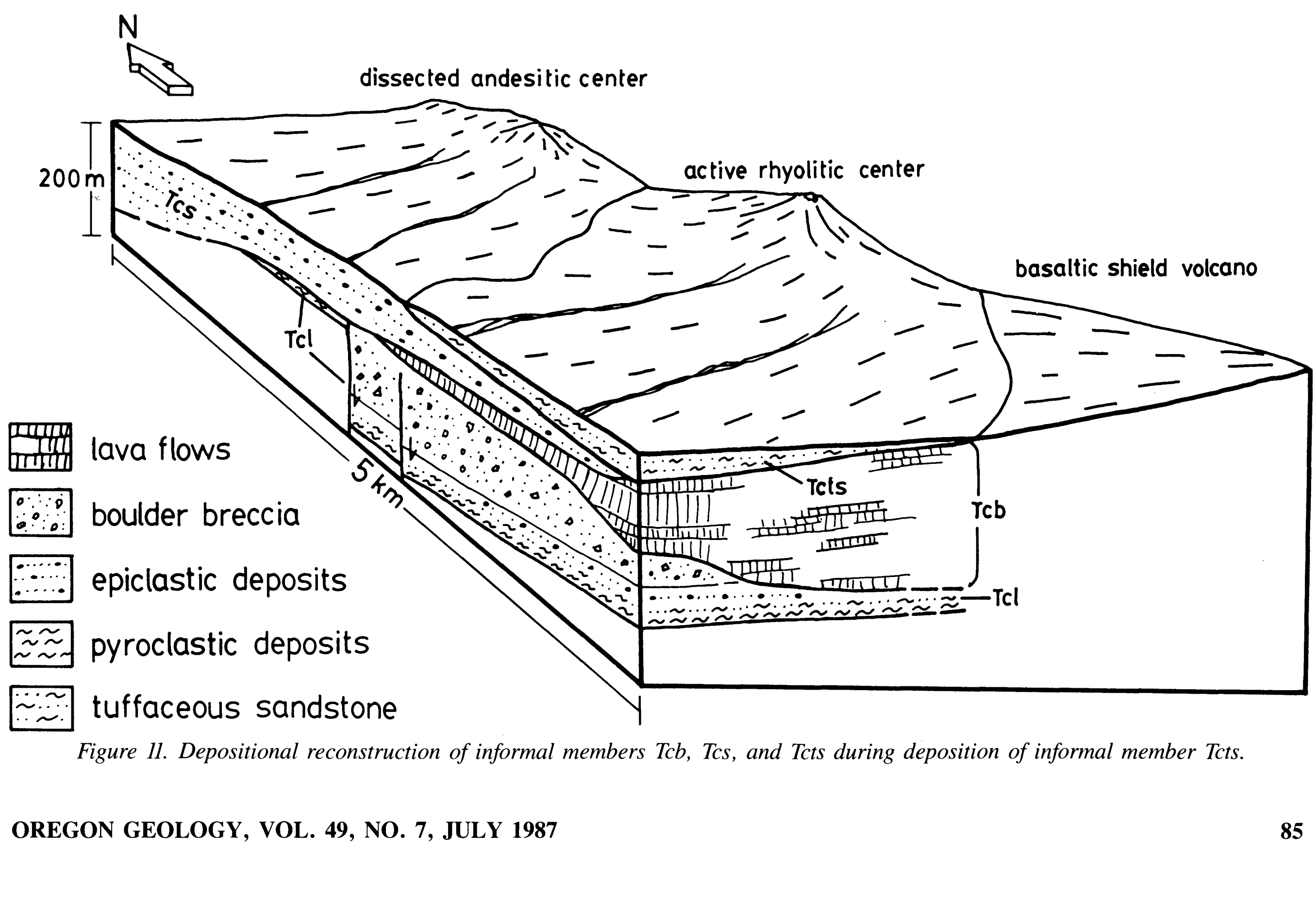


Figure 11. Depositional reconstruction of informal members Tcb, Tcs, and Tcts during deposition of informal member Tcts.

A regional north-south extensional stress, which formed east-west-trending grabens, could explain the pattern of basaltic and rhyolitic rocks at the base of the Western Cascades that is present to the north of the type area of the Colestin Formation. North of the Siskiyou Summit fault, a thick sequence of basaltic lava flows is present at the base of the Western Cascades (Roxy Formation). To the north of these basalts, however, a thick sequence of rhyolitic pyroclastic rocks, principally, the Bond Creek ignimbrite of Smith and others (1980), occurs at the base of the Western Cascades. These relations suggest that a regional east-west tectonic stress influenced the initial character of volcanism in the Western Cascades of southern Oregon. On the other hand, the graben faulting in the Colestin area may be the result of the uplift of the Klamath block and not related to this lithologic pattern at the base of the Western Cascades.

ACKNOWLEDGMENTS

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Bibliographic information on the geology and mineral resources of Oregon is now available for literature through 1984. The Oregon Department of Geology and Mineral Industries (DOGAMI) has published the eighth supplement in its series *Bibliography of the Geology and Mineral Resources of Oregon* as DOGAMI Bulletin 103.

Produced in cooperation with GeoRef, the computerized information system of the American Geological Institute, the 176-page document continues the periodic additions to the original 1936 work by R.C. Treasher and E.T. Hodge. The bibliography contains an author list with approximately 2,200 titles for the period of 1980 through 1984 and cross-references these entries in subject, county, and rock formation indexes.

The new DOGAMI Bulletin 103, *Bibliography of the Geology and Mineral Resources of Oregon, Eighth Supplement, January 1, 1980, to December 31, 1984,* is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $7. Orders under $50 require prepayment. □

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER FIGURE

Composite sketch of fluid-venting site 1428 on marginal thrust ridge on outer continental shelf off the coast of Oregon. Colonies of tube worms occupy the ledge above the canyon wall, and several clusters of giant white clams are aligned along presumed zones of fluid expulsion. The origin of the cone-shaped carbonate chimney structure with attached corals, which is shown at the top of this sketch, is discussed in paper beginning on the next page. Location of site 1428 is shown on Figure 4. Venting sites cover an area of about 20 m². (Figure from Suess and others, 1985, their Figure 1.)

In memoriam: Hollis M. Dole, 1914-1987

Hollis Mathews Dole, former State Geologist of Oregon and former Assistant Secretary for Energy and Minerals in the U.S. Department of the Interior, died of a heart attack on Monday, July 20, 1987.

Hollis M. Dole

Born in Paonia, Colorado, on September 4, 1914, Hollis moved to Oregon in 1917 and spent his childhood in various parts of the state, including Portland, Independence, and Grants Pass. He earned his B.S. and M.S. degrees in geology from Oregon State University and did additional work on economic geology at the University of California and the University of Utah.

After periods of employment with Bohemia Mines, Cottage Grove; American Trust Company, Palo Alto, California; the U.S. Bureau of Mines at Scappoose; and the U.S. Geological Survey at Tucson, Arizona; and after serving as a Navy lieutenant during World War II, Hollis came to the Oregon Department of Geology and Mineral Industries in 1948 when F.W. Libbey was Director. Upon Mr. Libbey's retirement in 1954, Hollis became head of the Department, serving as Director and State Geologist until March 1969.

During his tenure with the Department, Hollis initiated, among other things, the long-range investigation of the geothermal potential of Oregon. One of his proudest moments was in the summer of 1965, when the Department was the host for the first International Lunar Geological Field Conference, which was held in Bend. The conference was a huge success and put Oregon "on the map" among the geological fraternity for the first time.

In 1968, Hollis resigned his position with the State and was appointed Assistant Secretary for Energy and Minerals in the U.S. Department of the Interior. Following his government service, he

(Continued on page 98, ***Dole)***

Oil and gas news

Leadco, Inc., permits issued

Permits for two new Leadco, Inc., locations (June 1987 *Oregon Geology*) were issued on July 1. The locations, 3 mi northwest of Pittsburg in Columbia County, are scheduled to be drilled this season, according to the operator. Taylor Drilling will be the contractor.

Mist gas storage project update

The storage project at Mist is operated by Oregon Natural Gas Development and has been injecting gas since February 1987. The total gas injected into the Bruer and Flora Pools through May was 2.7 Bcf. The goal by September is a total of 5.5 Bcf, being added at a monthly rate of about 0.7 Bcf per month. Reservoir pressures at the end of the 1987 injection season will be 75 percent of original pressures. At present, all Mist production from other pools is being bought and stored in the Bruer and Flora Pools. □

Carbonate chimneys on the outer continental shelf: Evidence for fluid venting on the Oregon margin

by Nanci A.M. Schroeder[1], *LaVerne D. Kulm*[2], *and Gary E. Muehlberg*[3]

ABSTRACT

Three large, unique chimney structures were dragged from the seafloor by commercial fishermen about 32 km west of Cape Falcon on the outermost continental shelf off northern Oregon. They include one cylindrical and two conical chimneys from 1 to 2 m high that weigh from about 880 to 1,985 kg (400 to 900 lbs). The conical chimneys have a large internal cavity with openings at the top and along the side; the cylindrical chimney has a round, internal plumbing tube in the main chamber. All chimneys are composed chiefly of authigenic dolomite, with minor amounts of clastic particles. Stable carbon-13 and oxygen-18 isotope values of the carbonate range from -16.9 to -21.9 per mil and +7.62 to +7.87 per mil PDB, respectively. The shelf chimneys are similar in appearance and composition to carbonate chimneys discovered at active fluid vents with the *Alvin* submersible on the lower continental slope off central Oregon (Kulm and others, 1986). The sources of carbon for the vent carbonates are the methane and dissolved carbonate-bearing fluids being expelled from the pore waters in the underlying Pleistocene and Pliocene portions of the accretionary prism, whereas the source for the shelf chimneys is believed to be the pore waters of the older Oligocene to Miocene portions of the prism. The heavier carbon and oxygen isotope values of the shelf chimneys, compared to those on the slope (-32.5 and +6.2 per mil, respectively), suggest different sources and histories for the fluids from the two portions of the prism. We propose that the shelf chimneys form above the seafloor because of their shape, open plumbing network, and dominant authigenic carbonate composition. They serve as conduits to the overlying water column through which fluids flow from deep subsurface sources.

INTRODUCTION

During the summer of 1985, while dragging for bottom fish in an area known to Oregon coast fishermen as the "pinnacles", the vessel *Kodiak* entangled its net in seafloor rocks. With tremendous effort, the crew managed to salvage the damaged net and haul in the catch of the day: three very large rocks weighing nearly two tons. These chimneylike rocks were located in a water depth of about 247 m on the outer edge of the continental shelf, approximately 32 km west of Cape Falcon (Figures 1 and 2).

The unique physical characteristics of these rocks prompted the boat owners to notify the Geology Department at Clatsop Community College in Astoria, Oregon. The rocks were initially examined by Nanci Schroeder and Gary Muehlberg, who recognized them as chimney structures. It was obvious to them, however, that the chimneys were *not* the polymetallic sulfide chimneys typically found at hydrothermal vents on the Juan de Fuca Ridge some 500 km offshore (Normark and others, 1986). Because such chimney structures had not yet been reported from continental margins, it was not immediately clear how they came to be located in relatively shallow water so close to shore or how they were related to the geology of the surrounding seafloor. Therefore, a study was begun in the fall of 1985 to determine the nature and origin of the continental shelf chimneys. Interestingly, this study coincided with a similar discovery of chimney structures made on the lower continental slope off central Oregon with the aid of the submersible *Alvin* in August 1984 (Kulm and others, 1986). In this paper, we describe the characteristics of the shelf chimneys and compare them with those found in deeper water to determine their possible origin.

GEOLOGIC SETTING

Underthrusting of the Juan de Fuca Plate and consequent deformation and uplift of the North American Plate during the past 60 million years (m.y.) has developed a structurally and stratigraphically complex continental margin (Kulm and Fowler, 1974; Snavely and others, 1980). As clastic sediments are scraped off of the subducting oceanic plate, they are accreted onto the continental margin, producing an accretionary prism. This prism is comprised of a series of fold/thrust ridges, with intervening basins, striking subparallel to parallel to the Oregon-Washington margin (Figure 3) (Kulm and others, 1973a; Kulm and Fowler, 1974; Barnard, 1978; Snavely and others, 1980). Both seaward-verging (i.e., landward-dipping fault planes) and landward-verging (i.e., seaward-dipping fault planes) sedimentary sequences produce large anticlinal ridges. The most recently deformed ridges (< 2 m.y. old) lie farthest seaward at the toe of the continental slope (Figure 4) (Kulm and others, 1973b; Kulm and Fowler, 1974). Progressing landward, the ridges become successively older and more complexly deformed.

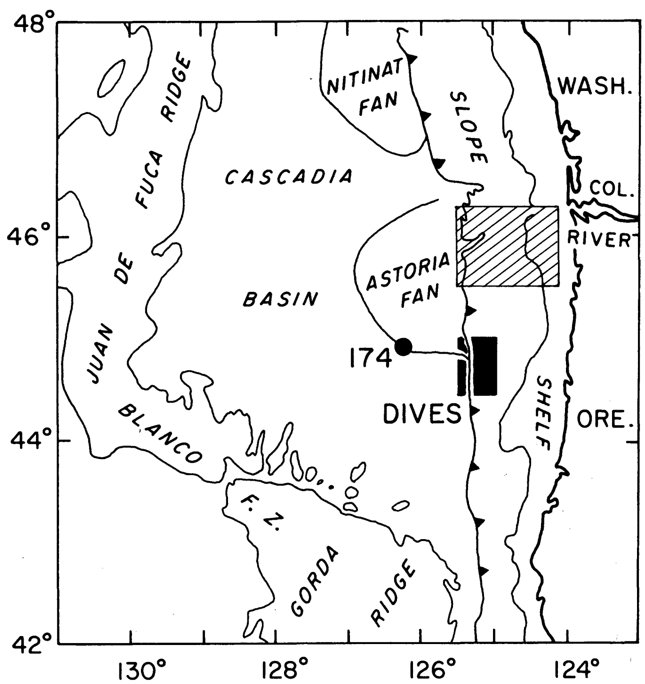

Figure 1. Location map of the Oregon continental margin (shelf and slope), Juan de Fuca Plate (Cascadia Basin), and spreading Juan de Fuca and Gorda Ridges. Subduction zone (saw teeth on upper plate) is located on the continental slope. Location of Deep Sea Drilling Site 174 on the Astoria Fan is shown by solid dot. The Alvin *dive area (labeled "dives") is shown by the black box. Study area is shown as lined box (see also Figure 2).*

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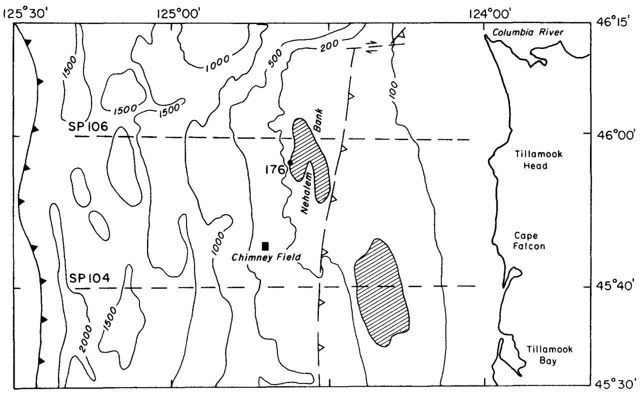

Figure 2. Map of the study area (modified from Peterson and others, 1986; see Figure 1 for location) on the continental shelf and slope off northern Oregon showing the location of the carbonate chimneys (solid square labeled "Chimney Field") on the outer shelf. Note the thrust boundaries between Juan de Fuca Plate and Oregon margin (solid barbs on upper plate) and between the accretionary prism (west) and the Eocene volcanic rocks with overlying younger basinal deposits (east) along the outer shelf (dashed line with open barbs). Lined pattern represents seafloor exposures of Miocene to Pliocene mudstone and siltstone with minor sandstone. Deep Sea Drilling Project (DSDP) drill site 176 is shown as solid dot. Locations of seismic reflection lines Sp-104 and -106 crossing the margin are indicated by dashed lines. Contours in meters. (See also Figure 3 for location of structures.)

Some of the most strikingly folded and faulted areas of the continental margin occur beneath submarine banks forming the outer edge of the continental shelf (Kulm and Fowler, 1974; Snavely and others, 1980). The chimneys described in this paper are located on the "pinnacles," an area that is better known as Nehalem Bank, on the outermost edge of the shelf (Figure 3). An Oligocene to Miocene accretionary prism underlies this portion of the bank and underthrusts the Eocene volcanic rocks to the east (Snavely and others, 1980; Peterson and others, 1986). Miocene to Pleistocene sedimentary deposits overlie the prism and contain unconformities that are late Miocene to late Pliocene in age (Kulm and Fowler, 1974).

RELEVANT OREGON SUBMERSIBLE STUDIES

Fluid venting sites were recently observed from the submersible *Alvin* on the lower continental slope off central Oregon (Kulm and others, 1986). They occur on the crest of a Pleistocene thrust ridge about 110 km to the south of the shelf chimney field at a water depth of 2,036 m (Figure 4). Each vent site is characterized by chemosynthetic-type animals, authigenic carbonate chimneys and slabs, and anomalous concentrations of methane (Figure 5) (Suess and others, 1985; Kulm and others, 1986; Ritger and others, 1987). Methane concentrations, which range from 180 to 420 nl/liter at 1 m above the seafloor at one vent site, are three to six times higher than those found in the ambient waters on the adjacent abyssal plain (Kulm and others, 1986). The methane is derived from the pore waters that migrate through the sediments of the accretionary prism that underlies the vents. The ultimate source of the methane-enriched fluids is the clastic sediment of the Astoria Fan (Figure 1), which has been accreted to the continental slope during the late Pleistocene.

Carbonate slabs (frequently concretions) are found a few centimeters beneath the sediment surface at each vent site, and the edges of the slabs are occasionally exposed on the seafloor (Ritger and others, 1987). Isolated, conical carbonate chimneys rise from 1 to 2 m above these sediment-covered vent sites (see cover figure). One isolated carbonate chimney occurs above a sharp-crested ridge on the second thrust ridge landward of the marginal ridge (Figure 4). All chimneys exhibit numerous cavities, grooves, and flutes, which have smoothly rounded edges giving the chimneys a "sculptured" appearance (Ritger and others, 1987). Each chimney is covered with numerous corals and sponges.

The two slope chimneys that were sampled consist chiefly of magnesian calcite, dolomite, and aragonite, with minor amounts of detrital clays, silt, and sand (Ritger and others, 1987). One sample contained abundant rounded and cemented mudstone pebbles and areas of pure carbonate cement, indicating an authigenic origin; another sample that consisted of finely cemented mudstone pebbles was also considered a typical authigenic carbonate.

The authigenic carbonates are being produced at each vent site from the methane-enriched pore waters that were being expelled from the underlying accretionary prism (Ritger and others, 1987). Stable isotope data indicated that the carbon in the carbonates came from a reservoir that was extremely depleted in carbon-13. Values of $\delta^{13}C$ of all carbonate samples collected on the margin range from -34.9 to -66.7 per mil PDB, which indicates a methane-derived carbon source (Ritger and others, 1987). The two slope chimneys that were analyzed have $\delta^{13}C$ values of -32.5 and -32.6 per mil and $\delta^{18}O$ values of +5.4 to +6.2 per mil. These more positive values indicate that the carbonates are marine, but they are also related to factors other than just the temperature of formation (Ritger and others, 1987), such as the history of the composition of the fluids (Suess and Whiticar, 1986).

CONTINENTAL SHELF CHIMNEYS

Physical description

The chimneys on the outer shelf range in height from 1 to 2 m (Table 1; Figures 5 and 6). The conical chimneys (Figure 5, chimneys 1 and 3) appear to be very similar in shape and size to those found on the lower slope; however, the cylindrical chimney (Figure 6, chimney 2) has, as yet, no counterpart in deep water. In general, each chimney has a hollow center, or vertical cavity, along with at least one large cavity in the side wall. Numerous smaller tubes penetrate the walls as well. Wall thickness varies greatly, from 3 to 30 cm; the walls are frequently cracked or broken. Surfaces are pitted and grooved, apparently from dissolution by seawater or by the habitation of benthic marine life. Chimneys 1 and 2 are similar in surface texture, coloration, and abundant biota. Chimney 2 is unique in that its cylindrical shape contains more small tubes and cavities than the conical ones. Situated within the hollow of the chimney is a secondary tube that runs parallel to the main cavity. This tube extends the length of the chimney, except where it is disrupted about one-third of the way up from the bottom. An opening in the outer wall reveals the inner tube, which appears to have collapsed against a blockage that fills the hollow. Chimney 3

Table 1. *Physical characteristics of the carbonate chimneys recovered from the outer continental shelf of northern Oregon. Dimensions given in metric system (meters and centimeters) and weight in English system (pounds).*

Characteristic	Chimney #1	Chimney #2	Chimney #3
Shape	conical	cylindrical	conical
Weight estimate	900 lb	400 lb	500 lb
Height	1.0 m	1.7 m	90 cm
Top diameter	40 cm	30 cm	30-50 cm
Base diameter	75 cm	30 cm	40-60 cm
Wall thickness	10-30 cm	3-15 cm	30-16 cm
Vertical vent hole diameter			
top	10 cm	13 cm	10 cm
base	30 cm	13 cm	18 cm
Color*	mostly lt gr N-7	same	same
	Br Gy 5YR 5/1**	same	same
Biological artifacts	abundant	abundant	common

* Geological Society of America color chart
** In vent holes

has a softer carbonate substance that can be easily scratched with a pocket knife. Dissolution features and surface discolorations are not as prominent as chimneys 1 and 2.

Still attached to the chimneys are the skeletons of encrusting corals and sponges. Calcareous and parchment-type worm tubes are abundant. Other noticeable biota include brachiopod shells and a few bryozoan colonies. Unidentified fossils and the tracks from burrowing organisms cover the chimneys.

Mineralogy and isotopic composition

Major-element chemistry (Table 2) and X-ray diffraction analyses show that the continental shelf chimneys consist chiefly of dolomite (69-89 percent carbonate), SiO_2 (14-22 percent), and Al_2O_3 (4-6 percent). All three chimneys are quite similar in chemical composition. Scattered quartz and feldspar grains as well as the tests of foraminifera occur within the carbonate matrix. Throughout the sampling process, there was no evidence of any embedded or cemented pebbles as found in the lower slope chimneys.

Table 2. *Major-element chemistry of three carbonate chimneys shown in Figures 5 and 6. Values are in weight percent.*

Component	Chimney #1	Chimney #2 (a)**	Chimney #2 (b)	Chimney #2 (c)	Chimney #3
$CaCO_3$ *	42.75	41.0	40.2	40.0	38.5
$MgCO_3$	34.16	31.0	27.5	30.0	26.7
$FeCO_3$	2.32	2.41	2.8	3.0	3.44
Σ Carbonate	79.2	74.4	70.5	73.8	68.7
SiO_2	14.2	15.9	17.9	18.4	22.8
Al_2O_3	3.93	4.22	4.77	5.0	6.49
Total Components	97.3	94.5	93.2	97.2	98.0

* calculated from acid soluble Ca, Mg, and Fe content

**samples 2(a) near bottom of outer chimney wall, 2(b) near top of outer chimney wall, and 2(c) upper portion of inner tube

The stable isotopic composition of the three shelf chimneys is quite similar (Table 3). The negative $\delta^{13}C$ values (-16.9 to -21.9 per mil) indicate that the carbon in these carbonates is moderately depleted in carbon-13. On the other hand, the large positive $\delta^{18}O$ values (+7.62 to +7.87 per mil) are heavier than those found in other authigenic carbonates on the Oregon margin (Ritger and others, 1987).

Table 3. *Stable carbon and oxygen isotopic values (per mil relative to PDB) of the carbonate chimneys described in Table 2.*

Chimney sample	$\delta^{13}C$	$\delta^{18}O$
#1	-21.9	+7.87
#2	-16.9	+7.28
#3	-20.5	+7.62

DISCUSSION

Comparison of structural-tectonic settings at venting sites

The lower continental slope carbonate chimneys are situated directly over the Pleistocene (vent sites 1426 and 1428) and Pliocene (chimney site 1423) portions of the accretionary prism. The prism is comprised of partly consolidated sands and muds derived from the adjacent Astoria Fan, whose deposits contain biogenic methane (McIver, 1973). In contrast, the chimney field on the outer shelf appears to be situated atop exposed, dipping sedimentary layers or diapiric structures that may be connected to the Miocene-Oligocene

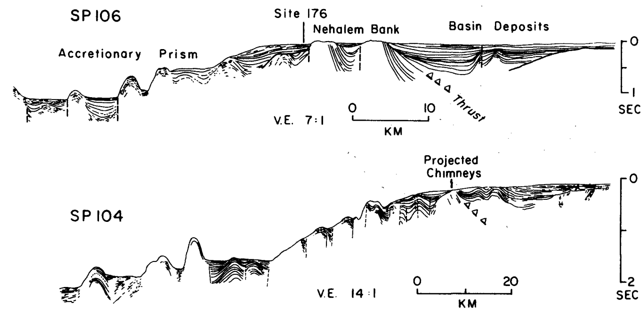

Figure 3. Line-drawing interpretations of Oregon State University single channel seismic reflection lines Sp-104 and -106 showing shelf basin deposits and accretionary prism. Dashed lines with open barbs show thrust boundary between the two features. See Figure 2 for location. Drill site 176 and the Nehalem Bank are indicated on Sp-106. Note projected location of carbonate chimneys over accretionary prism on Sp-104.

accretionary prism below (Figure 3). Pliocene fissile shale drilled on the outer edge of the shelf (Figure 2, DSDP site 176) shows that deep structures have been uplifted at least 500 m from a depositional site lower on the continental slope (Kulm and others, 1973b). Shallow-water megafossils and an angular unconformity between the upper Pleistocene clayey silts and the Pliocene shale indicate that the outer shelf has been truncated by a lower sea level and that it has most recently subsided more than 100 m with the subsequent deposition of Pleistocene shelf sediments. While the structural-tectonic setting of the outer shelf is more complicated than that of the lower slope, similar carbonate chimneys are forming in each area, indicating that the expelled fluids are derived from sediments of both the youngest and oldest portions of the accretionary prism off Oregon. In all areas, the chimneys apparently serve as conduits through which pore fluids from the prism are expelled onto the seafloor.

Chimney characteristics and internal plumbing

The carbonate chimneys found on the continental shelf and lower slope are similar in physical appearance and size, with the exception of the cylindrical chimney, which is unique among the venting structures discovered on the margin. The shelf chimneys exhibit an internal plumbing system consisting of small tubes and large cavities, whereas only small exterior holes could be observed from *Alvin* in the slope chimneys. This plumbing network permits the methane-enriched fluids, which are derived from permeable sand zones or fault zones within the underlying strata, to flow through the chimneys and precipitate the authigenic carbonate that forms the chimney. The flow probably emanates from holes in the top and side walls of the chimney, and precipitation occurs over the nearby external portions of the structure. The distribution of tubes within the cylindrical chimney suggests that precipitation patterns may periodically reroute the plumbing system, producing several tubes with external openings. It is clear from the cylindrical chimney that this precipitation can create extremely uniform tubes that themselves may become constricted as precipitation progresses (Figure 6, bottom left). The hollow cavity in the conical chimneys is larger at the base and smaller at the top, which suggests that the nature of the fluid flow and/or the precipitation pattern may control the dimensions of the hollow and the eventual shape of the chimney. While we, as yet, have no information on how the chimney is constructed by the precipitating fluids, it would appear that, as the flow slacks, the hole at the top may become smaller, and one would expect the internal cavity to become smaller as the fluids precipitate carbonate minerals. We speculate that there may be a relation between the nature of the internal plumbing system and the rate of flow of fluid through the structure. Given the same volume of available fluid, the conical chimneys may indicate a slow rate of flow whereas the cylindrical one, with its small internal tubes, suggests a faster rate of flow through the chimney.

Nature and sources of fluids

The sources of the precipitating fluids at the venting sites are the pore waters that were trapped within the clastic sediments of the accretionary prism. According to Ritger and others (1987), the methane in these fluids must be oxidized before the carbon is incorporated into the authigenic carbonate minerals that comprise the chimneys. Because of the presence of authigenic pyrite, which forms under anoxic sulfate reducing conditions within both the shelf and slope carbonates, the methane must be oxidized near the base of the sulfate reducing zone (usually a few meters or tens of meters subsurface) within the sediments beneath the chimneys. This oxidation probably occurs by a microbially mediated reaction related to sulfate reduction as given in equation 1:

$$CH_4+SO_4^{-2} \rightarrow HS^- + HCO_3^- + H_2O \quad \text{(equation 1).}$$

If sulfate is available within the deeper strata of the accretionary prism, it may also facilitate the methane oxidation during the upward migration of the fluids to the vent sites. The two possible sources of methane, biogenic and thermogenic, may be mixing at various levels in the prism during the migration process, producing the heavier $\delta^{13}C$ values (-16.9 to -21.9 per mil) determined for the shelf carbonates relative to the slope carbonates (i.e., biogenic methane has $\delta^{13}C$ values between -75 to -90 per mil [Claypool and others, 1973] and thermogenic -30 to -50 per mil [Vinogradov and Galimov, 1970]).

The mineralogy of all the chimneys is similar and consists essentially of dolomite and magnesian calcite. Minor terrigenous grains of quartz and feldspar are scattered through the carbonate matrix. This detrital material may be derived from the surrounding unconsolidated clastic sediments (Kulm and others, 1975) and plastered onto the chimneys by high-velocity unidirectional currents (up to

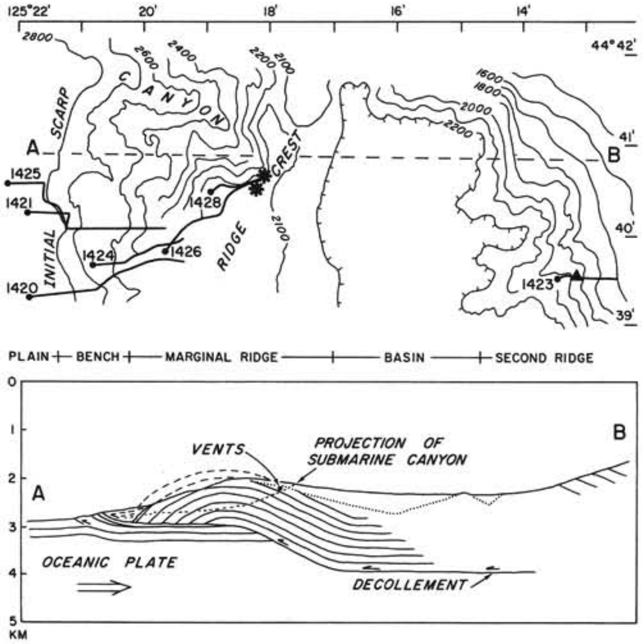

Figure 4. (Top diagram) Alvin *submersible transects and SeaBeam bathymetry map across the lower continental slope (see Figure 1, dive area). Contours in meters; numbered dives commence at the solid dots. Asterisks indicate fluid-venting sites and carbonate chimneys (i.e., northern site 1428 and southern site 1426 on marginal ridge); triangle indicates carbonate chimneys at site 1423 on the second ridge. (Bottom diagram) Interpretive structural depth section of the deformation front along profile A-B (dashed line across contour map at top). (From Kulm and others, 1986, their Figure 2)*

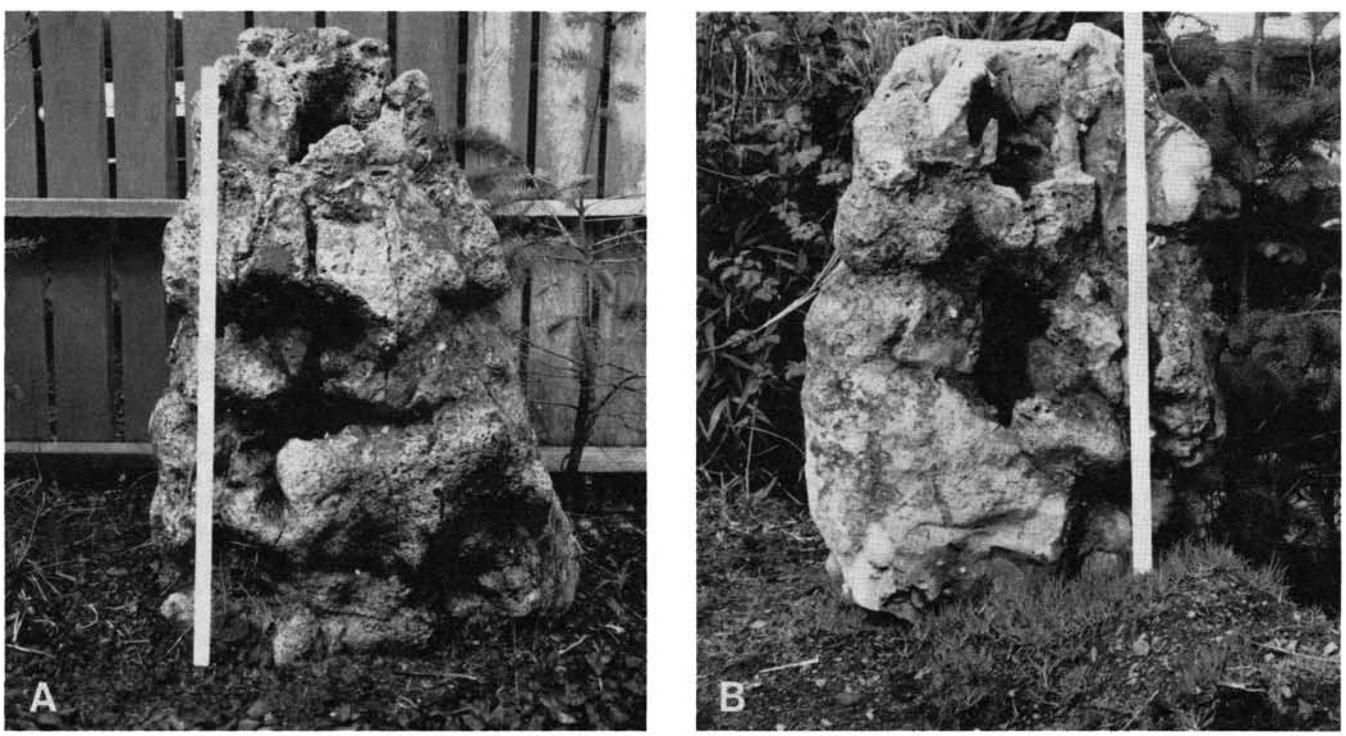

Figure 5. Conical carbonate chimneys (A=chimney 1; B=chimney 3) dragged from the outer continental shelf off northern Oregon. See Figure 2 for location designated "Chimney Field." Note conelike shape and large internal cavities viewed through openings in the side walls and top. See Table 1 and text for detailed description of chimneys. Scale is 1-m ruler.

40 cm/sec) sweeping the shelf (Smith and Hopkins, 1972) as the carbonate is precipitated in situ on the exterior of the chimney. Furthermore, the settling of sediment particles from the overlying water column off the Columbia River during the growth of the chimneys would impart a terrigenous component to their carbonate matrix.

One lower slope chimney contains mudstone pebbles that were not observed in the shelf chimneys, but Ritger and others (1987) believe that these pebbles are included in the cemented layers that form the basal part of chimney and that the upper portion may contain nearly pure carbonate.

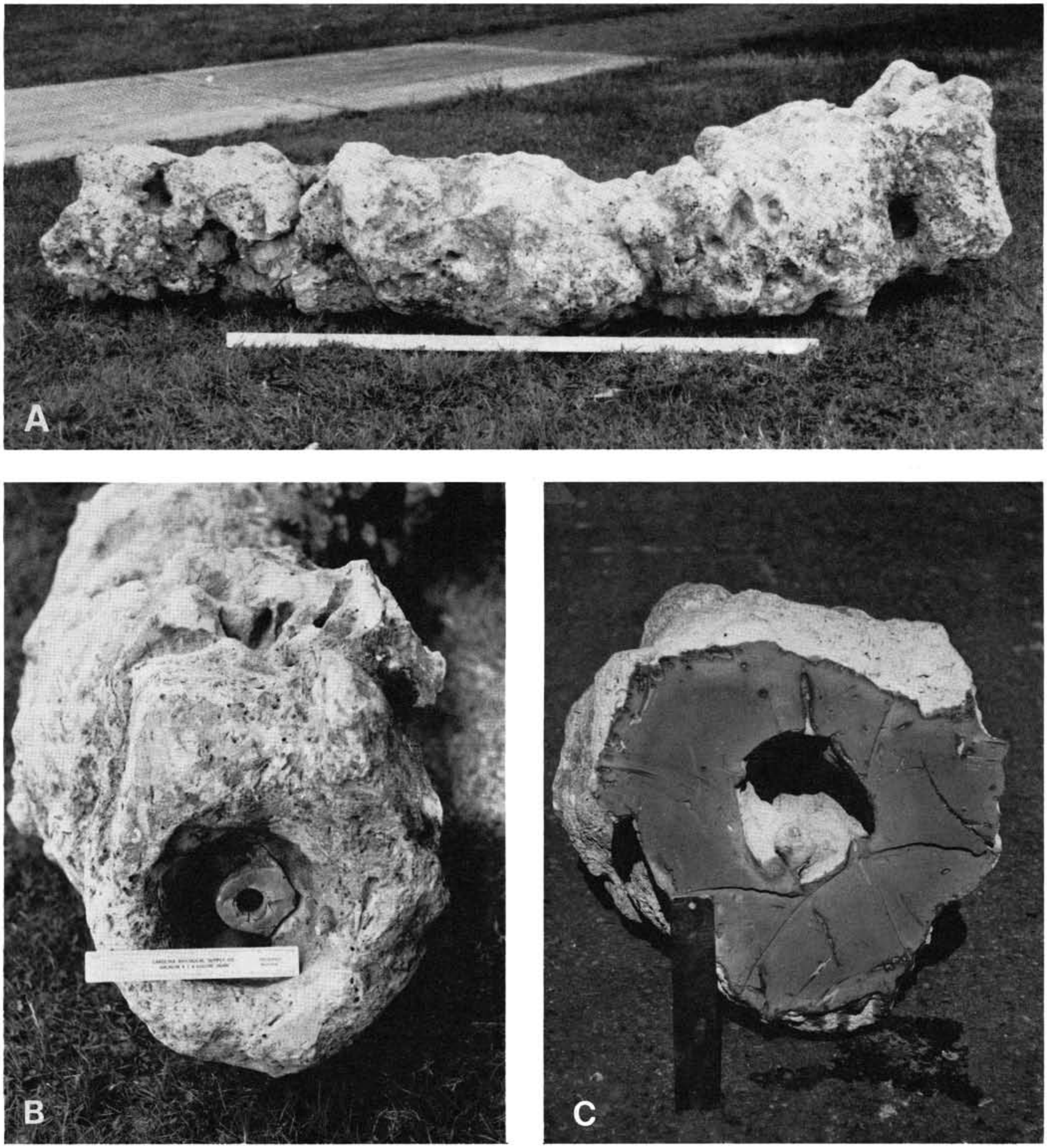

Figure 6. (A) Cylindrical carbonate chimney 2 (lying on its side), which was dragged from same location as conical chimneys (see Figure 2). It is not known which end is the top and which end is the bottom of the chimney, but for sampling purposes the top and bottom were arbitrarily chosen. (B) End view of cylindrical chimney; note internal cavity with its well-rounded, open plumbing tube that runs parallel to the main chamber. Scale is 6-inch ruler. (C) Cross-sectional cut of the smaller of the two ends of cylindrical chimney; burrowing animals produce grooves in dense carbonate lithology. See Table 1 and text for detailed description of chimney. Scale is 6-inch ruler.

Origin of shelf chimneys

Two logical hypotheses that have been proposed for the origin of the lower slope chimneys can also be applied to the shelf chimneys: (1) upward growth of the chimney above the seafloor, and (2) chimney formation below the seafloor within the sediment column with later exhumation by uplift and erosion (Ritger and others, 1987). The shelf chimneys consist largely of authigenic dolomite (69 to 89 percent) with patches of pure dolomite, suggesting a relatively minor terrigenous involvement in their origin. The terrigenous components could be added by sediment resuspension processes as noted previously or through the diagenetic replacement of terrigenous sediments by carbonate, producing chimneylike structures surrounded completely by terrigenous sediments. In the latter case, the terrigenous grains and foraminifera would be residual components of the replacement diagenetic process; the Pliocene to Pleistocene sedimentary deposits that are presently exposed on the shelf near the chimney field could be the host strata (Kulm and Fowler, 1974). If the shelf chimneys are formed by diagenetic replacement processes below the seafloor, it is difficult to reconcile the large cavities and small open tubes that characterize these structures. The tubes suggest that there is a uniform flow through the structures; this could not occur if the structure were encased within a sedimentary mass. In addition, the openings in the side walls of the chimneys appear to be primary features that developed as a result of uneven precipitation over the chimney. Alternatively, the openings could represent dissolution features, which were produced after the chimney was exhumed. But the continental shelf lies above the calcite compensation depth, so dissolution should not be that important in the alteration of the chimneys.

Considering all of the above factors, we believe that the shelf chimneys were formed above the seafloor and that they represent relatively recent venting of methane and dissolved carbonate-bearing fluids from the underlying Oligocene to Miocene accretionary prism. Carbon-14 dating of the carbonate carbon in a lower slope concretion at vent site 1428 reveals an age >40,000 years, but the calculated age based upon the sedimentation rates for the terrigenous sediments overlying it gives a much younger age of 2,500 years. The addition of old methane carbon from the deeply buried sources within the prism precludes the accurate dating of the carbonate chimneys. However, the shelf chimneys most likely formed sometime after the last erosional truncation event on the outer shelf, which was produced by one of the Pleistocene low sea level stands on the shelf.

CONCLUSIONS

1. One cylindrical and two conical carbonate chimneys were recovered from a water depth of 247 m on the outermost continental shelf off northern Oregon. They have an internal plumbing network consisting of cavities and/or small tubes with openings at the top and sides. They are quite similar in physical appearance to carbonate chimneys observed from a submersible at active fluid-venting sites on the lower continental slope and have given us first-hand evidence that fluids can be flushed through their plumbing system.

2. The chimneys consist largely of dolomite (69 to 89 percent), with minor amounts of terrigenous particles and foraminifera. Their $\delta^{13}C$ isotopic composition is noticeably heavier (-16.9 to -21.9 per mil) than other carbonate chimneys (-32.5 per mil) and concretions (-38.3 per mil) found at the venting sites on the lower slope. This indicates that the fluid sources of methane are different for shelf carbonates from those reported at the slope vent sites.

3. We propose that the shelf chimneys were constructed on and above the seafloor through dolomite precipitation from methane and dissolved carbonate-rich fluids that emanate from the chimneys. This hypothesis is supported by the open plumbing network, conical-cylindrical shapes, high mineral carbonate content, and stable carbon isotopic composition of the chimneys. The source zones of the fluids appear to be the Oligocene to Miocene accretionary prism strata beneath the chimneys. Updip migration along permeable horizons within the deeply buried accreted strata is the most likely source zone of fluids.

4. Fluid venting apparently occurs across the entire accretionary prism off central and northern Oregon from the late Pleistocene- to Oligocene-age strata. The carbonate chimneys provide a valuable geochemical record of this fluid expulsion.

ACKNOWLEDGMENTS

We acknowledge Bob's Net Shop, Inc., of Warrenton, Oregon 97146, the owners of the shelf chimneys who graciously allowed us to study and sample their unique find. We thank Andy Ungerer for the X-ray analysis and his assistance with geochemical studies. Erwin Suess provided valuable information on the interpretation of the isotopic data, and we appreciate his review of an early draft of the manuscript. His contribution to this study is gratefully acknowledged. Financial support for the project was provided by the National Science Foundation to L.D. Kulm through a grant (OCE-8215147-01,02-03) for the *Alvin* submersible work on the lower continental slope and by the Oregon State University Sea Grant program through a grant to L.D. Kulm for study of the fluid venting on the continental shelf.

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(Continued on page 98, ***Chimneys)***

Summary of symposium on Oregon's earthquake potential held February 28, 1987, at Western Oregon State College in Monmouth

by Robert S. Yeats, Department of Geology, Oregon State University, Corvallis, Oregon 97331

The problem with studying earthquakes in Oregon is that there are so few of them. A map recently released by the Oregon Department of Geology and Mineral Industries (DOGAMI), prepared by Randall Jacobson of Oregon State University (OSU), shows a few earthquakes, including an event of magnitude 5.5 near Portland, but the amount of seismicity in Oregon is low as compared to adjacent states. The instrumental seismicity of western Washington is moderately high, but in adjacent parts of northwestern Oregon, the seismicity is much lower. Finally, no obvious major active faults have been mapped onshore west of the Cascades.

But most participants in a February 28 symposium at the annual meeting of the Oregon Academy of Science at Monmouth indicated that the lack of earthquakes in Oregon is misleading. Preliminary evidence reported at the symposium suggests that western Oregon may have been visited by large earthquakes in the recent past.

Thomas Heaton of the U.S. Geological Survey (USGS) office at Pasadena pointed out the similarity of the Cascadia subduction zone off Oregon and Washington to the subduction zone off southern Chile. Like Oregon, the southern Chile plate boundary is marked by a sediment-filled trench with little topographic expression, low hills near the coast, a central valley like the Willamette, and volcanoes farther east. Until 1960, the plate boundary had another similarity—low seismicity, but the Chilean plate boundary ruptured in 1960, resulting in an earthquake with a magnitude of 9.5, the largest of the twentieth century. The subducting oceanic crust off Chile and Oregon is so young that it is still warm from being recently generated at an oceanic spreading center. Being warm makes the crust buoyant and hard to subduct, and thus it is expected to be strongly coupled to the overriding continental plate. When the bond between the two plates breaks, great earthquakes occur, at least in Chile, and possibly in Oregon as well. Heaton found similar correlations between young subducted crust and earthquakes off Colombia, Mexico, and southwest Japan. In contrast, old and cold oceanic crust is being subducted in the Marianas trench in the western Pacific. Because it is cold, the crust is heavy and sinks readily, and it is not well coupled to the overriding plate. Earthquakes occur there, but they are much smaller than those where subducting crust is very young, and much of the interplate slip is not accompanied by earthquakes. Since the Monmouth meeting, Heaton's findings have been published in *Science* (Heaton and Hartzell, 1987).

Until recently, aseismic slip was also thought to characterize the Cascadia subduction zone, and John Adams, now of the Geological Survey of Canada, found apparent support for this when he reported in 1982 that historic eastward tilt based on releveling of Coast Range highway survey monuments occurred at about the same rate as eastward tilt of Pleistocene terraces in the Coos Bay area. Adams pointed out that the Pleistocene terraces reach a zero isobase (no uplift or subsidence) not far east of the coastline, whereas the geodetic tilt reaches a zero isobase in Puget Sound and the Willamette Valley. For this reason, the comparison cannot be used as evidence for or against aseismic slip.

Robert Crosson of the University of Washington described a cross section of seismicity in the Puget Sound region that showed a gap between shallow earthquakes in the North American Plate and deep earthquakes in the underlying Juan de Fuca Plate. Crosson came to the remarkable conclusion that the plate boundary itself lies in the seismic gap and is not marked by earthquakes. Does this mean that the plate boundary is coupled, releasing only in great earthquakes? Why, then, is there so much seismicity within both plates and nearly none at the plate boundary?

There have been no great earthquakes in the recorded history of Oregon, but it should be noted that the record covers only about 175 years. Parke Snavely of the USGS at Menlo Park reported that the Indians of the Cape Flattery region of the Olympic Peninsula spoke of a great wave that occurred far back in their history and that most likely represented a tsunami from a large earthquake. Snavely also suggested that the two major mudflows that buried Indian longhouses at the Ozette site on Cape Alava may have been generated by earthquakes. Radiocarbon dating of cultural organic material, reported from this site by R.D. Daugherty and his graduate students at Washington State University, indicates that the oldest mudflow is about 800 years old and the youngest about 350 years old.

Brian Atwater of the Seattle office of the USGS has found evidence of prehistoric earthquakes expressed as coseismic subsidence or uplift.

Scientists have observed elsewhere in the world that prior to a great earthquake, the overriding plate near the trench is dragged down elastically toward the trench, but farther away from the trench, the overriding plate bulges upward elastically. During the earthquake, the plate boundary snaps, collapsing the bulge, and causing instantaneous uplift close to the trench. During the great Alaska earthquake of 1964, for example, much of the Kenai Peninsula and Kodiak Island dropped suddenly, drowning coastal villages, whereas offshore islands closer to the trench were uplifted suddenly, exposing the sea floor. Drowned marshes on the Kenai Peninsula are now overlain abruptly by barren sands and muds of the supratidal zone.

In early 1986, Atwater began in the state of Washington to compare historic evidence of differential uplift or subsidence with Holocene, prehistoric evidence. At Neah Bay, on the Olympic coast of Washington, he found a buried marsh surface very similar to those on the Kenai Peninsula. Later, at Willapa Bay, he found six cycles, with a characteristic succession consisting of an organic layer overlain abruptly by barren sand and mud, which grades upward into organic sediments containing rhizomes of marsh grass.

Atwater compared this cyclic succession with marsh sequences of stable coastlines and became convinced that a nonseismic origin such as megastorms or closing of a baymouth bar did not explain the abrupt upward change from organic marsh deposits to barren supratidal muds. His conclusion, later published in *Science* (Atwater, 1987), was that this abrupt change was due to sudden submergence during a great earthquake.

Curt Peterson of OSU and Mark Darienzo of the University of Oregon recorded the same abrupt change upward from marsh deposits to barren sandy muds in cores from Netarts Bay southwest of Tillamook in Oregon. At least five cycles of marsh development and burial were observed in the Netarts Bay marsh cores, and two subsidence events have occurred there in the past 1,500 years. It is not yet known whether the subsidence events recorded in the Netarts Bay marsh reflect instantaneous (coseismic) submergence or longer term episodes of submergence superimposed on a static or uplifting coast.

Unfortunately, the plate boundary megathrust is at the base of the continental slope and hard to measure directly. Snavely, however, showed seismic records with evidence of episodic Holocene thrusting and folding in the upper plate in many places on the continental slope and shelf. Furthermore, the plate boundary appears to come ashore south of Crescent City, California, where it has been studied by Gary Carver and his associates at Humboldt State University. Carver reported evidence of active Holocene thrusting and folding that accounts for much of the convergence rate between the Gorda and North American Plates. Trench excavations reveal displacements up to 4.5 meters (m) in individual faulting events, evidence that movement was jerky and coseismic rather than gradual and aseismic.

Evidence for faulting within the overriding plate was reported both onshore and offshore by Snavely, and he cautioned that warped marine terraces and a 1,700-year-old drowned forest at Neskowin may be due to local tectonics rather than deformation affecting the entire upper plate. Robert Yeats of OSU, building on earlier work of Marvin Beeson and his students at Portland State University, pointed out that linear ridges within the Willamette lowland, including the Portland Hills, Eola Hills, and Salem Hills, may mark active faults. Wendy Grant and Craig Weaver of the USGS Seattle office documented a linear zone of seismicity that extends under Mount St. Helens in which focal-mechanism solutions suggested right-lateral strike-slip faulting. Curiously, this shallow seismic fault has not been found at the surface.

The USGS has responded to the evidence for large earthquakes in the Puget Sound and Portland metropolitan areas. Albert Rogers of the USGS Denver office announced a new five-year program that would involve scientists from USGS, DOGAMI, and other institutions. For example, Alan Nelson of the USGS Denver office will be investigating the marshes between Coos Bay and Astoria for possible evidence for prehistoric earthquakes, and Steve Personius, also of the USGS Denver office, will study the long-term history of several Coast Range rivers to determine deformation styles and rates. The program will also evaluate seismic shaking potential for major urban areas of western Oregon and Washington.

In informal sessions preceding the symposium, participants observed that the low instrumental seismicity of western Oregon may be due in part to the small number of seismograph stations compared to adjacent states. A seismic network proposed for the Willamette Valley by Eugene Humphreys and Mark Richards of the University of Oregon probably would locate many earthquakes that now go unrecorded. In addition, such a network, when combined with existing stations in southern Washington, would allow the study of the crust and the plate boundary by the new technique of seismic tomography in which the crust and mantle are imaged by the distortion of seismic waves that pass through them.

Geodetic study of crustal deformation may provide one of the most critical clues to predicting a megathrust earthquake, according to Herb Dragert of the Pacific Geosciences Centre, Sidney, B.C. Recently completed geodetic measurements across Juan de Fuca Strait indicate that (1) horizontal shear strain is currently accumulating at a rate of about 0.2 ppm each year in coastal areas of northwest Washington and southwest British Columbia, and (2) Global Positioning Satellite (GPS) surveys can now be utilized to determine shear strain by resurveying older (pre-1950) triangulation control points. John Adams used highway releveling data from the Coast Range of Oregon and Washington for evidence of tectonic tilt, but he pointed out that many of these roads have not been releveled since the 1940's. A trilateration network measuring horizontal distortion does not exist in western Oregon.

The conveners, Robert S. Yeats of OSU and Donald A. Hull of DOGAMI, expressed hope that the conference would lead to an increase in neotectonic studies in western Oregon. The sites of active deformation reported by Parke Snavely onshore and offshore need to be examined in detail, looking for rates of deformation and individual deformation events. Perhaps in a few years, scientists can answer the question that was the title of the symposium: Could there be a devastating earthquake in Oregon?

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***(Dole,** continued from page 90)*

was placed in charge of the Colony Development oil shale program in Colorado. During the last ten years of his life, Hollis maintained a busy schedule as private consultant to several national and international organizations in the fields of energy and minerals.

Hollis is survived by his wife, Ruth, and two sons, Michael Hollis and Stephen Eric. We, his friends, will miss him.

—Andy Corcoran, former State Geologist

***(Chimneys,** continued from page 96)*

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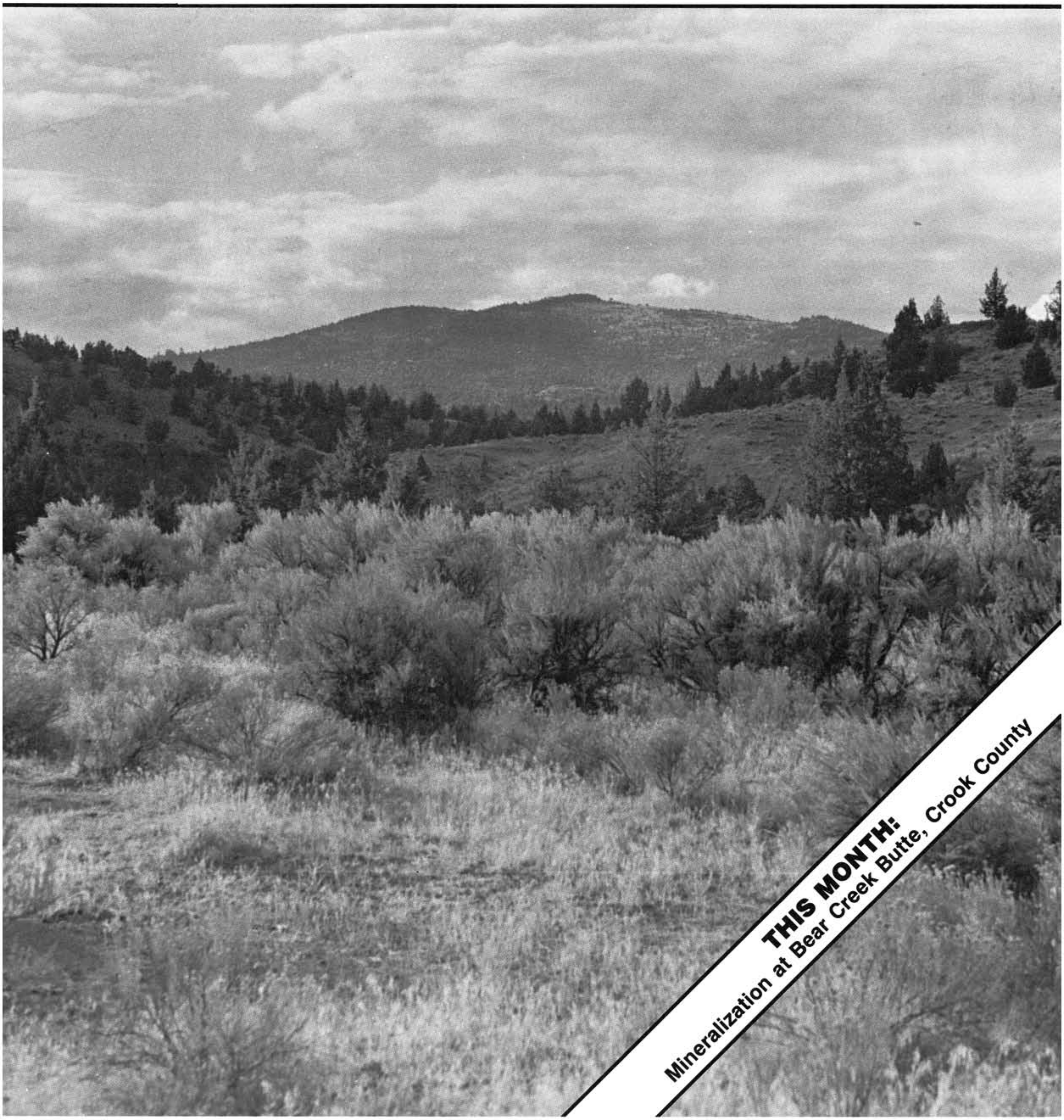

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Bear Creek Butte area, southwestern Crook County, Oregon, looking west toward Bear Creek Butte. Article on mercury and uranium mineralization in this area begins on next page.

OIL AND GAS NEWS

ARCO successful at Mist

ARCO Oil and Gas Company drilled the well Longview Fibre 11-31-64 to a total depth of 1,745 ft and has completed it as a gas producer from the Clark and Wilson sandstone. ARCO next drilled the Columbia County 11-34-65 to a total depth of 1,950 ft and has also completed it as a gas producer. Production rates have not yet been released for either well. These are the first two wells drilled by ARCO in its 1987 drilling program. The next well to be drilled is the Columbia County 31-27-65, permitted to a 7,000-ft depth, a relatively rare test to penetrate the deeper sediments at Mist.

Leadco well drilled

Leadco, Inc., drilled the CC-Jackson 22-17 to a depth of 2,318 ft and plugged and abandoned this well.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
392	ARCO Longview Fibre 32-20-65 36-009-00229	NE¼ sec. 20 T. 6 N., R. 5 W. Columbia County	Location; 2,850.
393	ARCO Col. Co. 21-35-65 36-009-00230	NW¼ sec. 35 T. 6 N., R. 5 W. Columbia County	Location; 1,900.
394	ARCO Foster 42-30-65 36-009-00231	NE¼ sec. 30 T. 6 N., R. 5 W. Columbia County	Application; 2,750.
395	Hutchins and Marrs GP 1 36-011-00024	NE¼ sec. 14 T. 30 S., R. 10 W. Coos County	Application; 6,000.

□

Lynch appointed MLR supervisor

Gary W. Lynch has joined the Oregon Department of Geology and Mineral Industries (DOGAMI) as supervisor of the Mined Land Reclamation Program located in Albany.

Lynch earned his bachelor's degree in economics at Colby College in Waterville, Maine, and did graduate work in range science at Montana State University. He joins DOGAMI after having served as reclamation specialist with the Montana Department of State Lands for nearly seven years.

His past experience as a reclamation specialist includes a wide range of supervisory, reclamation, and research-project responsibilities with the Montana Department of State Lands. An additional accomplishment of his career with that Department was the development of a remote sensing system to inventory mining activity throughout Montana.

In his new position, Lynch will supervise the Mined Land Reclamation Program, coordinate the Mined Land Reclamation Program with local, state, and federal agencies, investigate surface mining sites, and evaluate mining permit applications. Among his most immediate specific tasks will be the writing of administrative rules to deal with chemical leach mining and with revised bond requirements for aggregate mine sites. He also is looking forward to meeting with industry and government representatives in a series of regional meetings this fall. □

Mercury and uranium mineralization in the Clarno and John Day Formations, Bear Creek Butte area, Crook County, Oregon

by R. Matthew Wilkening and Michael L. Cummings, Department of Geology, Portland State University, Portland, Oregon

INTRODUCTION

Occurrences of the precious metals mercury and uranium have been reported from the Eocene to Oligocene Clarno Formation in the Ochoco and Blue Mountains; however, the metallogeny of this complex sequence of volcanic and volcaniclastic rocks is largely unknown. Prior to this study, the geology of the precious-metal mining districts was described by Brooks and Ramp (1968), mercury occurrences were described by Brooks (1963), and uranium occurrences were reported by Schafer (1956) for rocks of the Clarno Formation and the lower portion of the John Day Formation.

Hydrothermally altered rocks of the Clarno and John Day Formations are exposed in the Bear Creek Butte area, southwestern Crook County, Oregon (Figure 1). Prospecting for mercury began in this area during the late 1920's, and recorded production from the Platner and Oronogo Mines was 30 flasks. Brooks (1963), however, estimated production of about 45 flasks from the main producing mine, the Platner Mine. Schafer (1956) reported uranium exploration was primarily during the summer of 1955.

Mercury is one of the recognized pathfinder elements in exploration for gold in epithermal deposits. This association and the development of the McLaughlin Mine, one of the largest U.S. gold mines, at the site of the Manhattan mercury mine in northern California (Mining Engineering, 1986; Burnett, 1986) has resulted in evaluation of the precious-metal potential of mercury properties within Oregon. Several features associated with volcanic-hosted epithermal precious-metal deposits are present at Bear Creek Butte and indicate similarities to models developed by Buchanan (1981), Fournier (1983), and Berger and Eimon (1983) and as summarized by Tooker (1985).

STRATIGRAPHY OF THE BEAR CREEK BUTTE AREA

The rocks at Bear Creek Butte were assigned to the Eocene to lower Oligocene Clarno Formation by Lowry (1940). Wilkening (1986) recognized two sequences of rocks separated by an erosional unconformity, as indicated on the geologic map (Figure 2) and in the composite stratigraphic column in Figures 2 and 3.

Lower sequence of the Clarno Formation

The lower of these two sequences (Figure 2) is composed of basaltic andesite lava flows and intercalated mudflows and volcaniclastic sediments. Based on flow banding, topography, and the thickness and dip direction of lava flows, a volcanic center is inferred to underlie the northeast quarter of the area shown in Figure 2, where the flow section is at least 200 m thick.

Phyric flows are more abundant than weakly phyric flows. Clinopyroxene and plagioclase phenocrysts comprise 15 to 25 percent of the phyric flows and occur in a felty groundmass of plagioclase laths. The less phyric flows form cliffs and ledges and contain up to 10 percent of 2-mm-long plagioclase phenocrysts in a plagioclase-rich felty groundmass. Chemical compositions of these flows are presented in Table 1.

The mudflows contain carbonized wood fragments and subangular to subrounded cobbles to boulders of andesite in a matrix of sand and mud. The channel walls and irregular floors are exposed for some flows. The volcaniclastic sediments exhibit crude to well-developed bedding and cross-bedding and contain sparse leaf fossils that have been described by Mote (1940). Clasts include andesite lithic fragments, plagioclase crystals, and sparse quartz grains.

The lower sequence was eroded and deeply weathered to a dark-red, clay-rich zone prior to eruption of the upper sequence. This zone is thickest (up to 3 m) and best exposed in the south-central part of the area shown in Figure 2.

Upper sequence of the Clarno Formation

The upper sequence is a bimodal volcanic suite that includes basalt flows and the rhyolite flows that form two prominent buttes, Bear Creek and Taylor Buttes (Figure 2). The rhyolite flows display well-developed flow layering and contain up to 10 percent euhedral to subhedral plagioclase phenocrysts. Irregularly shaped, sparse

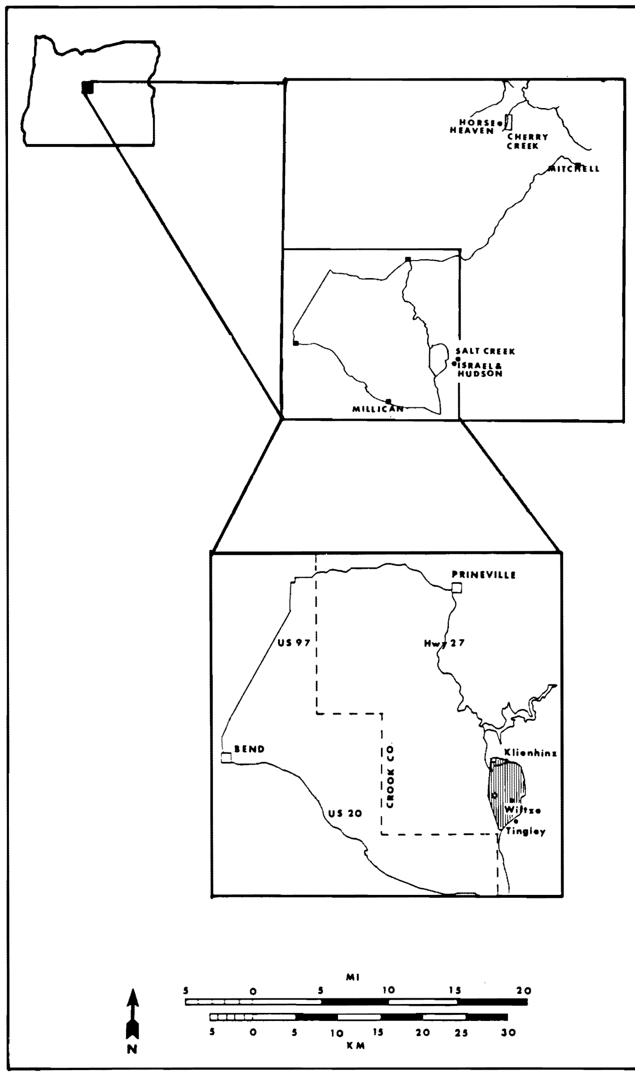

Figure 1. Location map for the Bear Creek Butte area in southwestern Crook County, Oregon.

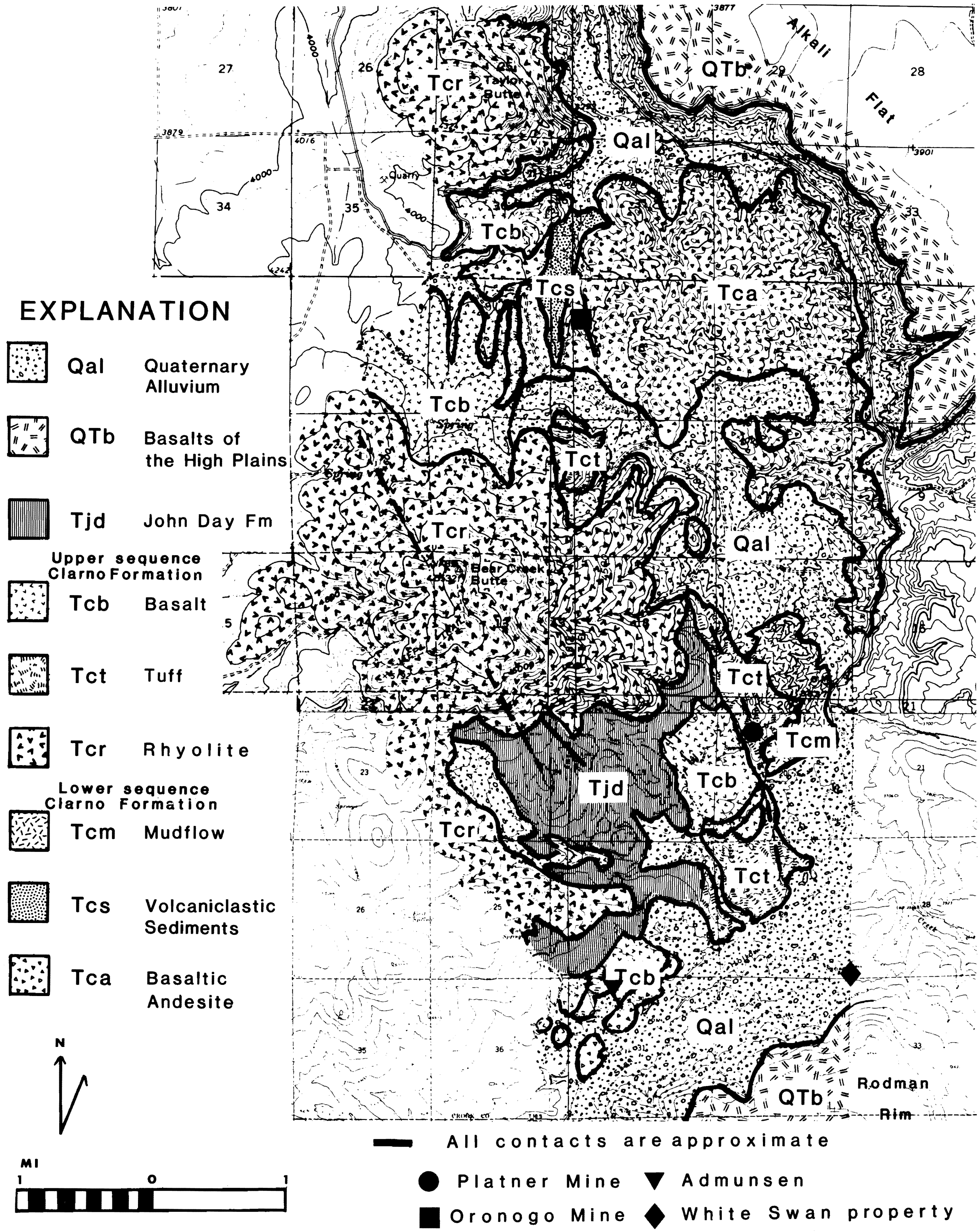

Figure 2. Generalized geologic map of the Bear Creek Butte area.

Table 1. Major-element geochemistry of basaltic andesites from the lower sequence of the Clarno Formation.

Major element oxide (Wt %)	Sample number 133	160	170	263	425	588	717	540
SiO_2	50.16	58.11	55.61	56.24	57.71	61.49	62.61	66.94
Al_2O_3	16.39	18.39	18.37	18.93	18.38	17.60	17.94	16.04
TiO_2	0.98	1.05	0.98	1.15	1.03	1.01	1.30	0.95
Fe_2O_3	4.43	3.06	3.66	3.72	3.43	2.89	2.73	2.85
FeO	5.08	3.51	4.19	4.26	3.93	3.31	3.12	3.26
MgO	9.13	2.96	5.35	2.30	3.02	2.44	0.28	0.42
MnO	0.17	0.09	0.16	0.12	0.09	0.10	0.06	0.23
CaO	10.59	7.56	8.39	9.11	7.21	5.69	6.79	4.48
K_2O	0.44	1.23	0.30	0.27	1.03	1.25	1.50	1.17
Na_2O	2.41	3.75	2.82	3.61	3.89	3.98	3.36	3.40
P_2O_5	0.21	0.27	0.18	0.30	0.29	0.26	0.31	0.27
Total	99.99	99.98	100.01	100.01	100.01	100.02	100.00	100.01

Sample locations: BCB-133 - SE, SE, NW, S. 7, T. 18 S, R. 17 E.: BCB-160 - NW, SE, SW, S. 8, T. 18 S., R. 17 E.: BCB-170 - SW, SW, SW, S. 31, T. 17 S., R. 17 E.: BCB-263 - NE, SE, NE, S. 6, T. 18 S., R. 17 E.: BCB-425 - SW, NW, NW, S. 9, T. 18 S., R. 17 E.: BCB-588 - SW, SW, SW, S. 36, T. 17 S., R. 16 E.: BCB-717 - SW, SE, NE, S. 20, T. 18 S., R. 17 E.: BCB-540 - SE, NE, SW, S. 36, T. 17 S., R. 16 E.

Major element concentrations determined by X-ray fluorescence at Washington State University, Department of Geology, Dr. Peter Hooper. Trace element and rare earth element concentrations determined by instrumental neutron activation are available upon request.

Table 2. Major-element geochemistry for samples from the upper sequence of the Clarno Formation.

Major element oxide (Wt %)	Sample number 45	63	112	143	385	84	325	655	195
SiO_2	75.38	72.70	75.25	80.19	76.61	49.94	48.78	49.09	56.41
Al_2O_3	13.46	13.77	14.01	10.54	13.54	16.10	17.05	20.73	18.03
TiO_2	0.29	0.31	0.24	0.23	0.25	2.42	2.62	1.88	1.04
Fe_2O_3	1.16	1.40	0.87	0.80	0.58	5.81	6.06	4.78	3.48
FeO	1.33	1.61	1.00	0.92	0.66	6.66	6.94	5.47	3.99
MgO	0.16	0.29	0.05	0.01	0.14	5.73	4.43	3.93	4.16
MnO	0.02	0.07	0.01	0.05	N.D.	0.16	0.24	0.16	0.14
CaO	0.72	1.03	0.16	0.19	0.28	8.94	8.87	9.60	6.72
K_2O	3.82	6.30	3.93	3.97	4.12	0.71	0.94	0.57	1.89
Na_2O	3.60	2.46	4.36	3.01	3.79	3.13	3.65	3.47	3.60
P_2O_5	0.06	0.06	0.12	0.08	0.03	0.40	0.41	0.31	0.53
Total	100.00	100.00	100.00	99.99	100.00	100.00	99.99	99.99	99.99

Sample locations: BCB-45 - NW, NW, SE, S. 13, T. 18 S., R. 16 E.: BCB-63 - SW, SE, SE, S. 13, T. 18 S., R. 16 E.: BCB-112 - SW, NE, NW, S. 25, T. 17 S., R. 16 E.: BCB-143 - NE, SE, SE, S. 12, T. 18 S., R. 16 E.: BCB-385 - NE, SW, SE, S. 25, T. 18 S., R 16 E.: BCB-84 - NW, SW, SE, S. 36, T. 17 S., R. 16 E.: BCB- 325 - NW, NW, NE, S. 30, T. 18 S., R. 17 E.: BCB-655 - NW, NW, SW, S. 20, T. 18 S., R. 17 E.: BCB-195 - SW, NE, NE, S. 31, T. 18 S, R. 17 E.

Major element oxides determined by X-ray fluorescence at Washington State University, Department of Geology. Trace element concentrations determined by instrumental neutron activation are available upon request.

vesicles are encrusted with iron oxides and are locally filled with quartz. Basalt flows and rhyolite tuffs are exposed on the lower flanks of the buttes. The basalt flows form iron-stained, low, fractured, knobby outcrops. Some low-volume flows contain plagioclase and traces of olivine in glomerocrysts within a felty groundmass of very fine-grained plagioclase laths and interstitial pyroxene. Other basalts, contain laths of plagioclase and up to 10 percent opaques, clinopyroxene, and intersitial olivine.

Two felsic tuffs, a welded tuff and a lithic tuff, cap ridges near Taylor and Bear Creek Buttes. The welded tuff is glassy and vesicular and contains sparse lithic clasts. Glass shards and small pumice clasts in a devitrified matrix are noted in thin sections. The lithic tuff is rich in lithic fragments and pumice clasts. Round lithic clasts of rhyolite that are similar to the rhyolite of Bear Creek Butte occur in the tuff. Table 2 contains geochemical analyses of the flows of the upper sequence of the Clarno Formation.

Along the lower slopes of Rodman Rim are outcroppings of vesicular, plagioclase-phyric, pyroxene-bearing andesite with red scoriaceous flow tops. These rocks underlie the basalts exposed in Rodman Rim and are believed to overlie the rhyolite of the upper sequence of the Clarno Formation. The composition of this unit is contained in the last column in Table 2. The rocks are similar to those described by Waters and others (1951) that overlie the rhyolites of their upper sequence of the Clarno Formation in the Horse Heaven mining area.

John Day Formation

An outlier of the Oligocene John Day Formation crops out southeast of Bear Creek Butte (Figure 2). The John Day Formation rests with angular discordance on the upper sequence and the dark red paleosol that mantles the andesites of the lower sequence. The John Day Formation here consists of three members. The lowest is a 10-m-thick, dark-reddish tuffaceous claystone and siltstone. The middle member is a pale-green tuffaceous claystone and siltstone. The tuffaceous sediments are capped by a welded ash-flow unit that is 3 to 6 m thick.

Basalts of the High Lava Plains

The cliffs and ledges of Rodman Rim (Figure 2) are formed by outcrops of vesicular basalts that underlie this part of the High Lava Plains. Alkali Flat (Figure 2) is formed by younger basalt flows that were erupted from a cinder cone located 8 km to the east. These basalts occupy a valley cut through the basalts that crop out along Rodman Rim.

HYDROTHERMAL ALTERATION

Three types of hydrothermal alteration have been defined, based on time of formation, alteration assemblage, and trace-element geochemistry. These types include (1) fumarolic alteration, (2) alteration associated with mercury prospects, and (3) alteration associated with uranium prospects. Zones of isolated, bleached, and vuggy fumarolic alteration are found on the slopes of rhyolite domes that form Taylor and Bear Creek Buttes and will not be discussed further.

Alteration of mercury prospects

Hydrothermal alteration associated with mercury prospects is located along northwest- and north-northwest-trending fault zones. The Oronogo and Platner Mines and the Admunsen Claims (Figure 2) are located in the areas of greatest hydrothermal alteration. Brooks (1963) described the geology of the Salt Creek, Hudson, and Israel Prospects located east of the study area, and their general characteristics are summarized in Table 3.

The hydrothermal alteration at mercury prospects in the Bear Creek Butte area has been divided by Wilkening (1986) into zones of strong, moderate, and weak alteration, based on the hydrothermal alteration mineralogy and preservation of primary rock textures.

The zones of strong alteration are centered around faults and form crude ellipses that are elongated along strike of the faults. Silicification in these zones varies in width from 3 m at the Oronogo Mine to more than 10 m at the Platner Mine. Abundant narrow quartz veinlets and silica flooding characterize the zone. Cinnabar occurs in the fine quartz veinlets that cut the silicified rocks. Fine-grained quartz has replaced all primary minerals, but iron oxides outline the primary mineral textures.

Hydrothermal breccias are restricted to the zones of strong alteration. These breccias consist of subangular to subrounded rock fragments ranging up to 0.25 m in diameter. The breccias have been sealed by very fine-grained quartz, and fragments display evidence of multiple episodes of brecciation. The breccias occur at the Platner Mine and Admunsen Claim along fault zones and are spatially associated with mafic intrusions.

The Platner Mine (Figure 4) is centered in the largest area of hydrothermal alteration. A lithic-rich tuff and glomeroporphyritic basalt flow of the upper sequence and a mafic intrusion comprise the lithologies affected by hydrothermal alteration. The zone of strong hydrothermal alteration is centered along faults trending N. 0°-15° W. and dipping 75°-85° to the west. Offset is not pronounced along these faults, but slickensides with variable but gentle plunge indicate late strike-slip motion. In the zone of silica flooding, the felsic tuff and mafic intrusion are replaced by fine-grained quartz and iron oxide. These materials have been brecciated and occur as fragments within a hydrothermal breccia. The breccia fragments also include previously brecciated tuff fragments. Younger cinnabar-bearing quartz veins cut the breccia. Similar patterns of alteration occur at the Admunsen Claim.

At the Oronogo Mine, the zone of strong alteration is restricted to narrow, $<$3-m-wide, elongate zones paralleling the strike of faults that cut lower sequence porphyritic andesite flows. Hydrothermal breccias and mafic intrusions are absent. Quartz veins vary from cockscomb growth along the vein walls to subhedral quartz grains that completely fill the veins. These veins rarely exceed 2 cm in width and host cinnabar mineralization.

The transition away from the silicified zone to the zone of moderate hydrothermal alteration is gradational as the ratio of clay to quartz increases. Moderate alteration is characterized by argillic alteration. Kaolinite is the most common clay; montmorillonite is associated with kaolinite at the Admunsen Claim. Clay minerals

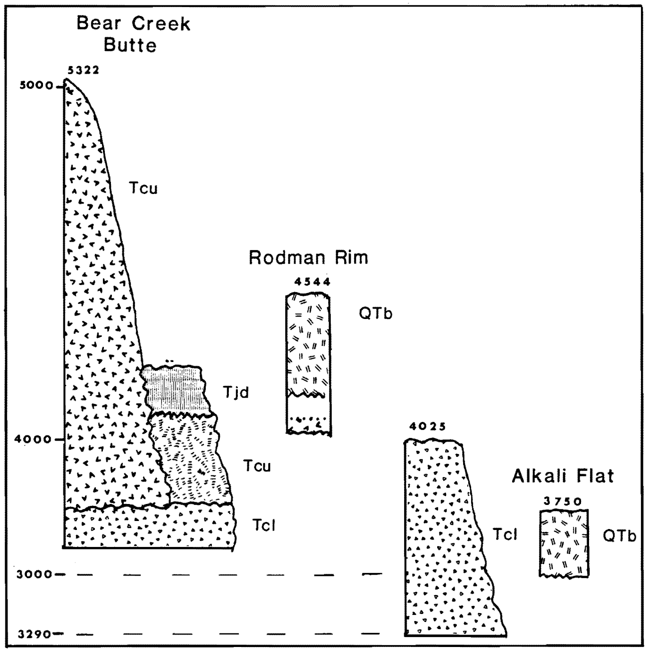

Figure 3. Generalized stratigraphic columns for various sections within the Bear Creek Butte area. Columns are indicated by elevation. Tcu=upper sequence of the Clarno Formation; Tcl=lower sequence of the Clarno Formation; other symbols same as in Figure 2.

replace much of the host rocks, leaving relic primary textures. At the Platner and Oronogo Mines, argillic alteration is more widespread in the hanging wall than in the footwall of controlling faults. Quartz veinlets are common, and, at the Platner Mine and Admunsen Claim, calcite forms stringers. Fine-grained limonite and hematite occur with clays and as fracture coatings.

The zone of weak alteration forms an irregular halo around the periphery of the zone of moderate alteration. The alteration is propylitic and contains chlorite, pyrite, carbonate, and clay minerals partially to totally replacing primary silicate minerals. In tuffs, pumice clasts and matrix are altered in patches, whereas less permeable lithic fragments are unaffected by alteration. Iron oxide coats fracture surfaces and, in thin sections, forms irregular masses and blebs. Locally the iron oxide pseudomorphs replace pyrite. Calcite is the most common carbonate, locally replacing the groundmass of the host rocks and occurring as fine stringers in felsic tuffs near the Admunsen Claim. Clay minerals cloud the groundmass and rim plagioclase phenocrysts in basaltic andesites at the Oronogo Mine.

Geochemical analysis of the alteration zones was performed using instrumental neutron activation analysis (INAA); selected data are included in Table 4. Bulk samples were collected along the strike of the fault zone to the north and south of the Platner Mine. In the area of the mine, grab samples were collected along three traverses run perpendicular to the fault trend. Arsenic and antimony concentrations decrease toward the south, away from the mine, and antimony concentrations gradually decrease away from the mine to the north. Mercury is irregularly distributed along the controlling structure and attains highest concentrations south of the Platner Mine.

The concentrations of arsenic, antimony, and mercury are lower at the Admunsen Claim. At the Oronogo Mine, concentrations of arsenic and antimony are low, whereas mercury concentrations are the highest encountered in this study.

Alteration of uranium prospects

The hydrothermal alteration zones associated with uranium prospects occur along northwest-trending ridges south of Bear Creek Butte and are controlled by northwest-trending faults. The host rocks are tuffs of the John Day Formation and rhyolites of the upper sequence of the Clarno Formation. The alteration zones are similar to those encountered at mercury prospects.

Geochemistry of the prospects indicates anomalous uranium concentrations six to ten times over background, with a high concentration of 59 ppm recorded in one sample. Arsenic and molybdenum concentrations are anomalous, but concentrations of antimony are generally very low (Table 5).

J. Gray of the Oregon Department of Geology and Mineral Industries sampled the area that bounds the study to the east. In one prospect, the White Swan property (Allen, 1939; Table 3), two samples of jasperoid float and a dump sample were collected. The data for these samples are contained in Table 6. The White Swan property lies along the extension of the northwest-trending uranium-bearing fault within the study area. The samples are relatively enriched in base metals but are also anomalous in uranium, molybdenum, and arsenic. Antimony is of low concentration. Data for other sites sampled by Gray are also presented in Table 6.

DISCUSSION

Stratigraphic relations

The stratigraphy of the Clarno Formation in the Bear Creek Butte area is similar to that described by other workers (Waters and others, 1951; Oles and Enlows, 1971; Noblett, 1981) in other areas of central Oregon.

Oles and Enlows (1971) described the stratigraphy of the Clarno Formation near Mitchell (Figure 1) in central Oregon and recognized two dissimilar sequences of rocks separated by an angular unconformity. The lower Clarno, composed of volcanic breccias, andesite flows, and varicolored tuffaceous sediments, is separated from the upper Clarno by a thick saprolite. The upper Clarno includes andesite lava flows and mudflows that were deposited upon a deeply eroded surface and, in places, occur as intracanyon deposits. One of the youngest units within the upper Clarno is a rhyolite-welded ash-flow tuff that locally caps ridges in the Mitchell area. These younger units appear to be unaffected by the deformation that in-

Table 3. Description of prospects from east of the study area.

Prospect name	Location	Structure	Lithology	Alteration	Reference
White Swan	S½ sec. 28, T. 18 S. R. 17 E.	NE - SW	White tuff	Veinlets of crystalline gypsum, last 8 ft of 47-ft shaft in pyritized Blue clay	Allen, 1939, unpublished DOGAMI report
Salt Creek	sec.3 T.18 S. R. 17 E.	N.10°E. dike cut by N.50°W. fractures	Andesite cut by andesite dike	silicification	Brooks, 1963
Hudson	E½NE¼ sec.9, W½ sec. 10, T. 18 S., R.17 E.	N.10°E., dips 75°E	Andesite flow over lithic tuff	Silicification, carbonate veinlets	Brooks, 1963
Israel	NE¼ sec. 9 T.18 S., R.17 E.	NW faults N fault	Andesite	Clays, limonite, mild silicification and carbonatization	Brooks, 1963

fluenced the Cretaceous section and the lower Clarno Formation.

Noblett (1981) indicated that the upper portion of the Clarno Formation is volumetrically small and that a thick saprolite and angular unconformity separate it from the lower Clarno in the area of Cherry Creek (Figure 1). In that area, the upper Clarno Formation is composed of andesite flows and tuffs.

In the Horse Heaven mining district, Waters and others (1951) indicated a thick sequence of Clarno rocks that they divided into four units: andesite, tuffs and volcanic mudflows, tuffs, and rhyolitic tuff. A thick saprolite is developed on these units and separates them from a more nearly flat-lying sequence of lavas that unconformably overlie the four units. The upper sequence includes a "basaltic andesite" that is distinct from those andesites below the unconformity. These "basaltic andesites" contain numerous altered ferromagnesian phenocrysts, lack plagioclase phenocrysts, and were partially eroded before eruption of rhyolite flows, ash-flow tuffs, and tuffs. These deposits are locally buried beneath a younger set of unaltered, vesicular "augite andesites." These rocks contain plagioclase and augite phenocrysts and sparse xenocrysts of quartz. Swanson and Robinson (1968) assigned the "basaltic andesites," rhyolites, and "augite andesites" to the upper Clarno Formation. This was based on a radiometric age determination of 41.0 ± 1.2 m.y. for a porphyritic rhyolite flow at the Horse Heaven Mine.

The thickness of the Clarno Formation in the Bear Creek Butte area is not known, since the base is not exposed. The basaltic andesites, mudflows, and volcaniclastic sediments of the lower sequence are similar to those described by Waters and others (1951), Oles and Enlows (1971), and Noblett (1981) within the lower portion of the Clarno Formation. Although a thick weathered zone or saprolite is present, an angular unconformity between the lower sequence and the rocks included in the upper sequence at Bear Creek Butte does not appear to be present.

The lower sequence of the Clarno Formation ranges in chemical composition from basalt to dacite, with basaltic andesite the most abundant rock type. These rocks belong to the high-alumina calc-alkaline intermediate rock series, and data from this study are in general agreement with those obtained by Oles and Enlows (1971), Novitsky-Evans (1974), Huggins (1977), Owen (1977), and Rogers and Novitsky-Evans (1977a,b) for the lower Clarno Formation in the Mitchell area.

The rocks included in the upper sequence are a bimodal volcanic suite of subalkaline rhyolite and low-potassium, high-titanium basalt. Petrographically, this association is similar to the "basaltic andesite-rhyolite" suite described by Waters and others (1951) in the Horse Heaven mining area; however, at Bear Creek Butte, the basalts not only underlie but are interlayered with the felsic pyroclastic rocks erupted from Taylor and Bear Creek Buttes.

The augite andesites described by Waters and others (1951) may be similar to the unaltered, vesicular andesite sample BCB-195 (Table 2). However, in the Bear Creek Butte area, this andesite directly overlies the andesites of the lower sequence rather than the rhyolite-basalt suite of the upper sequence. The phenocryst content, lack of alteration, vesicular nature, and red scoriaceous flow-top rubble are similar in the rocks from the two areas.

The distance between the Bear Creek Butte area and those areas of the Clarno Formation that have been previously studied precludes correlations because of the laterally discontinuous nature of volcanic deposits. It may be stated that, at Bear Creek Butte, (1) the lower sequence is composed of lavas of basalt, andesite, and dacite composition; (2) deformation of the lower sequence prior to eruption of the upper sequence is not noted; (3) a thick weathered zone separates the upper and lower sequences and is believed to mark the same stratigraphic level as the one noted in the Mitchell-Horse Heaven mining areas; and (4) the upper sequence is composed of rhyolite and basalt flows and rhyolite tuffs.

Table 4. Selected geochemical data for mercury prospects in the Clarno Formation.

(1)	(2)	(3)	(4)
Oronogo mine area			
Hg	6/9	0.1- 4.4	1.0 ppm
As	3/9	1.5- 3.9	2.3 ppm
Sb	8/9	6.7- 22.0	14.9 ppm
Admunsen claim			
Hg	5/9	0.1- 2.4	0.6 ppm
As	8/9	1.0- 43.1	11.6 ppm
Sb	8/9	1.0- 56.0	29.4 ppm
Platner mine area			
Hg	14/40	0.1- 1.0	0.3 ppm
As	33/40	1.1- 50.0	11.4 ppm
Sb	31/40	0.8-102.0	37.0 ppm

(1) Element of interest.
(2) Number of samples with element above background / total number of samples analyzed.
(3) Range of concentrations above background: background determined from fresh rocks from the altered unit.
(4) Average concentration of samples above background. Concentrations determined by instrumental neutron activation analysis. N.D.= not detected. Hg concentrations are normalized against an internal standard. As and Sb concentrations are given in ppm.

Hydrothermal alteration

Mercury prospects: Temperature, pressure, rock type, permeability, fluid composition, and duration of activity are recognized as playing important roles in development of epithermal mineral deposits. The composition and temperature of hydrothermal solutions responsible for mineralization at Bear Creek Butte were not directly determined in this study. Based on the work of Roedder (1967), White and others (1971), Taylor (1974), Rose and Burt (1979), and Mariner and others (1983), it is believed that the mercury mineralization at Bear Creek Butte originated from hydrothermal fluids that were dilute alkali-chloride solutions of meteoric waters within a temperature range of 150°-300 °C.

Boiling of hydrothermal solutions is associated with several important processes including changes in pressure and temperature, hydrothermal brecciation, fractionation of volatile components into the vapor phase, and increasing salinity of the fluid phase. Self-sealing and local separation of carbon dioxide from the fluid lead to pressures greater than rock strength. This leads to rupture, boiling of solutions, and, under the correct conditions, hydrothermal brecciation. Repeated cycles in the same area concentrate metals and, given adequate time, result in the eventual formation of an ore deposit. Fluctuations in the level and thickness of the zone of boiling influence the volume of the mineralized zone and thus the tonnage of the deposit.

Blakestad and Stanley (1986) argued that only prograding geothermal systems possess the geochemical attributes capable of forming near-surface economic mineralization. Prograding systems are those with steep geothermal gradients associated with the rise of intrusions to shallow levels in the crust. Monotonic systems, those characterized by static and low geothermal gradients, are not favorable for forming economic deposits.

Mercury, arsenic, and antimony are commonly associated with epithermal precious-metal deposits. Mercury is a volatile element that is readily transferred into the vapor phase when boiling occurs. To transport mercury, the hydrothermal solution must be reducing enough to keep mercury in solution as Hg^0_{aq} (Verakamps and Buseck, 1984). Upon boiling, mercury is carried in the vapor toward the surface as Hg^0_{vap}. Vapor transport results in formation of mercury halos as well as flux of mercury to the atmosphere. Cinnabar cannot occur in vapor-dominated systems and requires participation from an aqueous phase. Deposition of mercury as cinnabar requires turning Hg^0_{aq} into Hg^{++}. This conversion may occur in response to mixing with oxidizing or acidic water. The association of cinnabar + hematite ± pyrite indicates oxidized or sulfur-poor solutions.

Arsenic and antimony are commonly found in geothermal systems associated with mercury and in hot-spring precious-metal deposits. Christensen and others (1983) found that arsenic reflected the geometry of fluid-flow controlling structures at the Roosevelt Hot Springs Thermal Area, Utah. Somewhat higher concentrations were detected within the upper and more altered portions of wells. Antimony was found in low concentrations and was concentrated within a narrow zone in the upper levels of the geothermal system. These elevated concentrations were found to be largely coincident with silicification.

Evaluation of the potential for epithermal precious-metal mineralization involves recognition of those features in the rocks that indicate both the extent to which the aforementioned processes have been active and the distribution of elements of geochemical interest.

At Bear Creek Butte, hydrothermal alteration is structurally controlled, and the lateral extent of alteration is a function of the permeability of the host lithology. Where the host rocks are tuffs, as at the Platner Mine, the alteration zones are wide and extend up to 85 m from the controlling faults. At the Oronogo Mine, where the host rocks are andesite flows, the alteration is restricted to a narrow zone along the faults. Cinnabar occurs in quartz veins cutting silicified rocks in the zones of strong alteration.

The hydrothermal system that formed the mercury prospects at Bear Creek Butte was driven by mafic intrusions. As these intrusions rose along fault zones, the ground water was heated. Probably separation of CO_2 from the fluid and local trapping of this gas allowed lithostatic pressure and tensile strength of the rocks to be exceeded. This allowed rupture of the rocks, violent decompression, and development of hydrothermal breccias. Boiling of the solutions may have fractionated some mercury into the vapor phase to produce the geochemical anomaly in the altered zone. The final emplacement of the dikes was followed by continued hydrothermal activity, as sulfur-poor fluids carried mercury leached from the country rocks deep within the system toward the surface to become mixed with near-surface, cool, and oxidized water, that precipitated mercury as cinnabar in chalcedony and quartz veins in silicified breccias. The kaolin and quartz alteration and pseudomorphic replacement of pyrite suggest that the prospects may be near the paleosurface that existed at the time of alteration.

Table 5. Selected geochemical data for uranium prospects in the John Day Formation.

Sample Number	As	Sb	U	Th	Mo
CA-M	2.2	0.9	5.3	5.2	N.D.
190	2.7	0.3	4.9	19.1	N.D.
191	3.7	0.3	4.6	18.7	N.D.
193	92.3	N.D.	43.0	7.5	1.0
194	153.7	N.D.	28.0	14.6	1.2
194B	7.9	0.3	6.4	17.6	N.D.
196B	15.8	N.D.	59.0	12.2	1.1

Mo concentrations are normalized against sample 193. Mercury concentrations were below detection limits for instrumental neutron activation analysis. N.D. = not detected.

The lack of detectable gold by INAA (detection limit of 0.05 ppm) in the alteration zone and veins is disappointing; however, if gold were deposited at the zone of boiling associated with development of hydrothermal brecciation, a precious-metal zone might occur at a deeper level than the rocks exposed at the present erosion surface.

Uranium prospects: The uranium prospects at Bear Creek Butte are characterized by the geochemical association of uranium and molybdenum in hydrothermally altered felsic tuffs. Analogous settings are the uranium deposits in the Lakeview uranium district, Oregon, where the host rocks are peraluminous rhyolites and tuffs that Castor and Berry (1981) tentatively correlated with the John Day Formation. At Lakeview, secondary mineralization occurs along limonitized and/or silicified shear zones in bleached ash-flow tuffs. This alteration mineralogy is similar to that found in the prospects at Bear Creek Butte. The source of uranium is believed to be the tuffs of the John Day Formation, with deposition occurring within structural sites where oxidized solutions became reduced and allowed deposition of uranium and molybdenum (Zielinski, 1981).

This environment of deposition is distinct from the oxidizing conditions required for deposition of mercury in the mercury prospects. The fault trend at the uranium prospects also differs from the controlling fault trends in the mercury prospects, which are more north-northwest to northwest. From these data, it is interpreted that the uranium was not deposited within the same system that formed the mercury deposits.

TIMING OF MINERALIZATION

The timing of mineralization of the two systems is not certain. The mercury system, which may be as old as the Eocene or early Oligocene, developed during volcanism that deposited the upper sequence of the Clarno Formation. An upper age on mineralization can be set only as the age of the younger plateau basalts, since nowhere in the study area does the alteration cut rocks of the John Day Formation allowing a more precise bracketing of the age of alteration. The uranium-system alteration is within the John Day Formation and is not related to Clarno volcanism. The controlling northwest fault coincides with a lineation in the plateau basalts of Rodman Rim that is visible on Landsat imagery. Thus the uranium mineralization may have developed as recently as late Miocene or Pliocene.

CONCLUSIONS

1. The Clarno Formation in the Bear Creek Butte area is composed of a lower sequence of basalt, andesite, and dacite flows, mudflows, and volcaniclastic sediments and an upper sequence of basalt-rhyolite and younger andesite. The two volcanic sequences are separated by a paleosol.

2. The basalt-rhyolite association of the upper sequence of the Clarno Formation at Bear Creek Butte is similar to that at the Horse Heaven mining area.

3. Mercury mineralization as cinnabar is hosted in quartz veinlets cutting silicified hydrothermal breccias that developed ahead of basaltic intrusions. The present erosion level in these deposits is believed to be near the paleosurface at the time of mineralization. Precious metals may occur at deeper levels in the system but were not detected by surface geochemical sampling.

4. Uranium mineralization is minor and developed under differing conditions from the spatially associated mercury mineralization. Uranium occurs in the tuffs of the John Day Formation and may have developed during the late Miocene or Pliocene.

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Table 6. Geochemical data for samples collected by J. Gray, Oregon Department of Geology and Mineral Industries, 1984.

Trace element in ppm	Sample number 388	389R01	389R02	390R01	391R01	391R02	392R01	393R01
Au	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Ag	0.16	0.15	0.13	0.12	0.21	0.14	0.13	0.14
As	9	15	3	12	29	10	19	3
Hg	0.53	0.20	0.11	0.52	0.30	0.10	0.30	0.06
Cu	12	7	11	12	8	12	14	51
Pb	40	15	10	4	6	9	15	4
Zn	139	133	193	52	65	135	68	58
Mo	3.2	3.5	4.8	6.4	3.9	3.1	17.1	1.7

Sample locations: 388R01 - NE, SW, NE, S. 35, T. 17 S., R. 16 E.: 389R01 - NW, NW, SW, S. 36, T. 17 S., R. 16 E.: 390R01 - NW, NW, NE, S. 36, T. 17 S., R. 16 E.: 391R01 - NE, SW, NE, S. 36, T. 17 S., R. 16 E.: 391R02 - NW, NW, NE, S. 36, T. 17 S., R. 16 E.: 392R01 - SW, SW, NW, S. 28, T. 18 S., R. 17 E.: 393R01 - SW, SW, SW, S. 28, T. 18 S., R. 17 E.

Figure 4. Abandoned workings of the Platner Mine. Silicified hydrothermal breccias and narrow basalt dikes form the ridge crest.

by the first author. An early draft of the manuscript was reviewed by Jerry Gray and Edward Taylor. Their comments have helped to improve the paper.

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Geologist Board accepts new structure

The Oregon Board of Geologist Examiners has tentatively approved the transfer of its administration from the former Department of Commerce to "independent state agency" status. This change was provided for in Senate Bill 1034, passed by the Oregon Legislature and signed by the Governor in July.

The Geologist Board's budget for the biennium 1987-89 will remain unchanged, according to Dr. Allen F. Agnew, Chairman. Because the work load of the Geologist Board does not require a full-time administrator, it was decided that the Geologist Board should contract for its administrative services with the staff of the Board of Engineering Examiners.

Agnew reported to the Geologist Board that he had met with Edward B. Graham, Executive Secretary of the Board of Engineering Examiners, to work out the details of the transfer of administrative services. Graham is a registered Land Surveyor in the State of Oregon, through the Board of Engineering Examiners.

The new arrangement, the Geologist Board agreed, should provide economic services and convenience for both boards. Further information is available from Administrator Graham or Judy Holan, Room 403, Labor and Industries Building, Salem, OR 97310, phone (503) 378-4180.

The Geologist Board has scheduled its next examination for potential registrants for October 30-31.

—Board of Geologist Examiners news release

Oregon DEQ announces open position

The Oregon Department of Environmental Quality (DEQ) is seeking to fill the following position:

Hydrogeologist (Geologist 4) position, compensation $2,483-$3,158 per month, with the State of Oregon, Department of Environmental Quality, in Portland. The position is with the Solid Waste Program of the Hazardous and Solid Waste Division.

The Hydrogeologist serves as the program's expert in determining the accuracy and adequacy of reports, normally submitted by consultants, that describe hydrologic conditions below solid waste facilities; a further responsibility of the position is the monitoring of programs developed to detect contamination.

DEQ is an equal opportunity employer. For further information, contact the DEQ personnel office, 811 SW 6th Avenue, Portland, OR 97204, phone (503) 229-5110. □

Plan for scientific drilling in the Cascades released

Broad outlines of a program for scientific drilling for the Cascade Range (PSDC) in Oregon, Washington, and California and a detailed plan for the first phase of this comprehensive scientific investigation have been published by the Oregon Department of Geology and Mineral Industries (DOGAMI) in a new open-file report.

The report, DOGAMI Open-File Report O-86-3, is entitled *Investigation of the Thermal Regime and Geologic History of the Cascade Volcanic Arc: First Phase of a Program for Scientific Drilling in the Cascade Range.* It was prepared for the U.S. Department of Energy by DOGAMI geologist George R. Priest with contributions by 23 other geologists from a variety of state and federal agencies and academic and private research institutions.

The 120-page report includes descriptions of the objectives and priorities of all three anticipated phases of the PSDC. For the first phase, it presents specific discussions of 11 tasks of implementation, as well as a management plan and a scheduling and budget plan. Drilling and extensive geologic and geophysical surveys are proposed for a representative segment of the volcanic arc in the vicinity of Santiam Pass and Breitenbush Hot Springs. The final phase would culminate in the drilling of an ultra-deep drill hole to depths of 7-10 km. The report contains new data on the Cascade Range and numerous illustrations, including geophysical models and generalized geologic maps. An extensive bibliography on Cascade research is also included.

The PSDC report is the result of nearly three years of planning by scientists from state and federal geological surveys, universities, and national laboratories. The PSDC plan was developed as part of the national Continental Scientific Drilling Program which is administered by the U.S. Department of Energy, the U.S. Geological Survey, and the National Science Foundation. The proposed studies are intended to serve as a framework for specific proposals for studies in the future.

The new report, Open-File Report O-86-3, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $9. Orders under $50 require prepayment. □

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COVER PHOTO

Aerial view of Fossil, Oregon, looking to the north. Middle and upper parts of center show Wheeler High School and the outcrop of John Day Formation at the north end of the school's athletic field. Article discussing fossil plants from this outcrop begins on next page. Photo courtesy Douglas Watson.

OIL AND GAS NEWS

ARCO continues at Mist

Since successfully completing its first two 1987 wells at Mist, the Columbia County 11-34-65 and the Longview Fibre 11-34-64, ARCO is drilling a deep test at the Columbia County 31-27-65. This well, permitted to a 7,000-ft depth, is a relatively rare test to penetrate the deeper sediments at Mist.

Damon to deepen well

Damon Petroleum Corporation plans to reenter the Stauffer Farms 35-1 well. This well, located in sec. 35, T. 4 S., R. 1 W., Marion County, was drilled to a depth of 2,752 ft and was suspended in December 1986. Damon plans to reenter and deepen the well. Permit depth is 2,900 ft for this Willamette Valley test.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
396	Interwest Exploration Cavenham 33-1 36-007-00018	SW¼ sec. 5 T. 6 N., R. 7 W. Clatsop County	Application; 8,000.
397	Damon Petroleum Corp. Stauffer Farms 35-1 D 36-047-00020-80	NW¼ sec. 35 T. 4 S., R. 1 W. Marion County	Location; 2,900.

□

New geologic map for Baker County gold mining district released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new geologic map of the Elkhorn Peak 7½-minute quadrangle. The area is part of the Rock Creek- Sumpter-Baker gold mining district. It also contains limestone deposits from which chemical-grade calcium carbonate has been produced in the past.

The new release, *Geology and Mineral Resources Map of the Elkhorn Peak Quadrangle, Baker County, Oregon,* is map GMS-41 in DOGAMI's Geological Map Series and was prepared by geologists M.L. Ferns and H.C. Brooks of DOGAMI, D.G. Avery of the USDA Forest Service, and C.D. Blome of the U.S. Geological Survey (USGS). It is part of an ongoing mapping program partially funded by the USDA Forest Service and also represents the first DOGAMI map published in part under the COGEOMAP program of the USGS.

The map area is located just west of Baker and includes the southeast portion of Elkhorn Ridge between Rock Creek and Phillips Lake. It is geographically rugged—with over a mile of relief—and geologically complex, containing rocks that represent fragments of ocean floor and island arcs rafted against the North American continent 100 to 160 million years ago.

The full-color map (scale 1:24,000) shows rock units and geologic structure on a topographic base and identifies zones of mineralization, mines and prospects, and locations of rock samples and fossils. It is accompanied by three geologic cross sections, a discussion of mineral deposits, and a table describing 67 known mines and prospects in the area. A separate sheet contains a detailed sample location map and descriptive and analytic tables for rock samples and fossils.

The new map, GMS-41, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $6. Orders under $50 require prepayment. □

Oligocene fossil plants of the John Day Formation, Fossil, Oregon

by Steven R. Manchester, Department of Geology, Indiana University, Bloomington, Indiana 47405, and Herbert W. Meyer, Museum of Paleontology, University of California, Berkeley, California 94720

ABSTRACT

Fossil plants from an exposure of John Day Formation in Fossil, Oregon, are identified and discussed in relation to vegetational and climatic interpretations of the Bridge Creek flora. The assemblage includes about 35 species, most of which belong to genera that are no longer native to the Pacific Northwest. Some of the genera are extinct, but most survive today in eastern Asia and/or eastern North America. The flora is dominated by broad-leaved deciduous elements such as alder, maple, beech, and an extinct hornbeam but also includes conifers such as dawn redwood and pine. The flora appears to represent a deciduous hardwood forest comparable in stature to the Mixed Northern Hardwood forest living today in eastern Asia. This suggests a climate somewhat cooler than that proposed for other localities of the Bridge Creek flora.

INTRODUCTION

One of the most readily accessible and well-collected fossil-plant localities in Oregon is located within the John Day Formation in the town of Fossil (Figure 1). The fossil beds were exposed during the construction of Wheeler High School in 1949 and are still accessible at the north end of the athletic field (SW¼NW¼ sec. 33, T. 6 S., R. 21 E., Wheeler County). Although the locality has been collected by amateurs and professionals on a continuing basis for more than 35 years, relatively little information has been published on the types of fossils that are preserved and on the nature of the forest that left this record. Brown (1959) illustrated and briefly discussed the remains of an unidentified bat from this site along with plants from this and other sites in the lower part of the John Day Formation. Naylor (1979) described a species of salamander (*Taricha lindoei*) from Fossil. The present paper reviews the geologic setting and approximate age of the locality and focuses on the taxonomic identity of plant specimens from the locality at Fossil in order to provide insight into the kind of forest represented and its relationship to other paleofloras of the John Day region.

The fossil flora and fauna of the John Day Formation have attracted interest for more than a century. The town of Fossil received its name in reference to fossil remains found on what is now Hoover Creek, where the original Fossil post office was established in 1876, prior to the incorporation of the community at its present location in 1891 (Steiwer, 1975). The first descriptions of fossil plants from the John Day Formation were published by Newberry (1883, 1898), based upon specimens collected by Rev. Thomas Condon in thc 1860's from the classic locality on Bridge Creek (also referred to as Wade's Ranch and Allen's Ranch; Chaney, 1948a). The Bridge Creek locality, which also provided specimens described by Knowlton (1902), is located about 25 miles south of Fossil and is now protected as part of the John Day Fossil Beds National Monument (Painted Hills Unit; Figure 1).

Fossil leaf beds have been discovered at widely scattered locations in the lower part of the John Day Formation in north-central Oregon and have been broadly referred to as the Bridge Creek flora (Chaney, 1952; Wolfe and Tanai, 1987), although the extent of their similarity in age and species composition to the classic Bridge Creek locality remains to be documented. Chaney (1927) published the most complete analysis of the flora, focusing on localities in the Crooked River basin. More recently, Ashwill (1983) called attention to related fossil plant localities on Gray Butte in the lower part of the Crooked River basin.

In the years that have elapsed since the most recent overall treatment of the Bridge Creek flora (Chaney, 1927), approaches to the identification of fossil plants have changed considerably, resulting in more reliable determinations based on detailed studies of leaf, fruit, and flower morphology. Individual species of the Bridge Creek flora have been periodically revised (Brown, 1939, 1946, 1959; Tanai and Wolfe, 1977; Wolfe, 1977; Manchester and Crane, 1987; Wolfe and Tanai, 1987), but a complete revision of the flora has not been done. To the extent possible in a paper of this length, we attempt to provide an update on the identity of Bridge Creek taxa through critical evaluation of the systematic affinities of the species known from the locality at Fossil. An interpretation of the type of vegetation and climate represented by the flora as well as theories regarding its origin are also presented.

Although the classic Bridge Creek locality is now closed to casual collecting, new specimens are continually collected at Fossil, and we expect that this account of the flora may appear incomplete as the investigation of newly recovered material proceeds and as private collectors share some of their finds with the scientific community. By illustrating the common elements of the flora, we hope to aid casual collectors in determining when they may have found something new or unusual.

GEOLOGIC SETTING

The fossil locality occurs in bedded lacustrine tuffs (i.e., lake-deposited volcanic ash) of the John Day Formation. The John Day Formation is exposed over an extensive area in north-central Oregon and generally lies above the Clarno Formation of Eocene age and below the Miocene Columbia River Basalt Group. It ranges in age from Oligocene to early Miocene with radiometric dates from 37 to 19 million years (m.y.). In general, the fossil-leaf-bearing horizons of the formation are early Oligocene in age (as per the chronology of Berggren and others, 1985) and occur stratigraphically below the succession of late Oligocene to Miocene beds that produce the well-known John Day vertebrate faunas (Woodburne and Robinson, 1977).

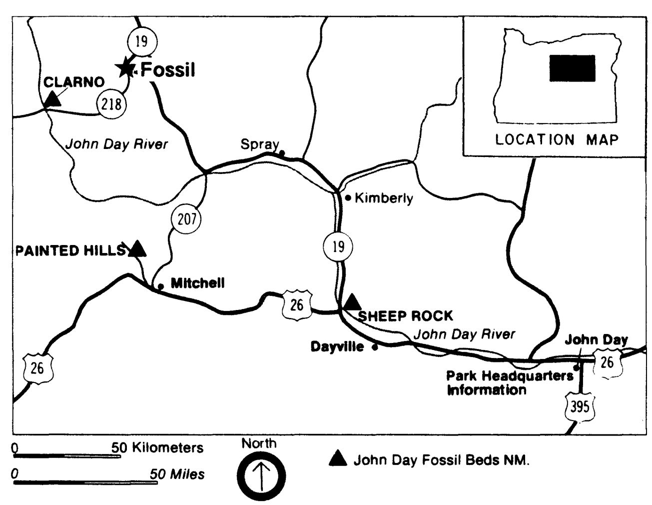

Figure 1. Index map showing location of Fossil in relation to John Day Fossil Beds National Monument.

Rocks comprising the John Day Formation were derived from at least three separate source areas, each producing lithologies of a particular composition (Robinson and Brem, 1981). Rhyolitic ash-flow tuffs and lava flows were erupted from volcanic vents east of the present-day Cascade Range, along the western margin of the John Day Formation outcrop area. Basalt and trachyandesite flows were derived from local sources near their outcrop areas. Dacitic to andesitic air-fall material is abundant and widespread throughout the formation and is believed to have originated from volcanism in the area of the Western Cascade Range during the early formation of these mountains. This air-fall material includes volcanic ash that was important in the preservation of plant and animal remains. The most informative paleobotanical localities, such as the one at Fossil, represent lake basins into which ash was redeposited along with plant debris from the surrounding forest.

Based on differences in thickness and upon the distribution of ash-flow sheets, the John Day Formation has been divided into three geographically separate but lithologically similar facies (Robinson and others, 1984), which suggest that the Blue Mountains formed a topographic barrier that separated different basins of deposition. Each of these facies contains important fossil plant horizons in its lower part. The western facies includes the locality at Fossil and those of Cove Creek and Dugout Gulch (data for these localities in Chaney, 1927), Knox Ranch (Arnold, 1952), and Gray Butte (Ashwill, 1983; McFadden, 1986). The eastern facies includes the fossil plant localities at Bridge Creek, Cant Ranch, and Twickenham (Chaney, 1948a). The southern facies, situated south of the Ochoco Mountains, includes localities along the Crooked River referred to as Gray Ranch and Post (Chaney, 1927).

The vicinity surrounding the John Day locality in Fossil is mapped as Clarno Formation (Robinson, 1975), but the stratigraphic relationship of the fossil outcrop to other units of the John Day Formation needs further study. Although radiometric dates are not available from the immediate vicinity of Fossil, the floral assemblage is similar to, and may be approximately contemporaneous with, the classic locality at Bridge Creek, which is radiometrically dated at 31.8 and 32.3 m.y. (Evernden and others, 1964; corrected to new constant). Other localities of similar lithologic and floral character (Pentecost Ranch, Cove Creek, Knox Ranch, and Dugout Gulch) occur between the basalts of members b and f (Robinson, 1975) of the John Day Formation northeast of Clarno, and a radiometric date for the base of the overlying member g is 30.4 m.y. (Woodburne and Robinson, 1977; new constant).

FOSSIL PLANTS

The fossils are preserved as impressions and carbonaceous compressions in laminated to massive tuff. In addition to the remains of leaves, the deposit contains abundant fruits, cones, seeds, and occasional flowers. Specimens are recovered either by examining surface material or by breaking the rock parallel to the bedding plane with hammer and chisel. Because the rock has many vertical fracture planes, some of the larger leaves can be collected only by carefully removing and gluing together adjacent pieces of rock as they are exposed in the bedding plane. The matrix is often soft, and the delicate impressions are easily damaged; therefore it is important to wrap the specimens carefully before transporting them.

Our analysis of the flora is based upon collections at the University of California Museum of Paleontology (UCMP) and upon collections at Indiana University (IU) that we made during the summer of 1986. Based on these collections, the assemblage from Fossil includes about 35 species, including a fern, three conifers, a monocotyledon, and about 30 dicotyledons; a few of which remain unidentified. The specimens in Figures 2 to 6 are all from the locality at Fossil and are illustrated actual size (1 X) unless otherwise indicated. Captions for Figures 2 to 6 include the UCMP and IU specimen numbers. The most abundant fossils at the locality are leaves of *Metasequoia* (Figure 2D), *Alnus* (Figures 5A,B), and *Paracarpinus* (Figure 5E) and fruits of *Acer* (Figures 6F,G) and *Pteleaecarpum* (Figures 6L,M). Authors of species are presented in Table 1, and the following discussion is arranged according to the sequence of genera also presented in Table 1.

Lower vascular plants are uncommon in the flora. Only one fern has been recognized, based upon a single specimen (Figure 2A) of a fertile entire-margined pinnule showing two rows of circular sori and a strong midvein. Sporangia and spores are not preserved, but the arrangement of the sori is similar to that in some living species of *Polypodium.* This species has not been observed in other localities of the John Day Formation, although one other fern was described as *Pteris silvicola* from Gray Ranch (Chaney, 1927).

Conifers in the Fossil assemblage include *Abies* (fir), *Pinus* (pine), and *Metasequoia* (dawn redwood). Foliage of *Metasequoia* is common at this locality (Figure 2D), especially as isolated needles, and both seed (Figure 2B) and pollen cones (Figure 2C) also occur. From a historical standpoint, *Metasequoia* is one of the most interesting plants found at this locality. *Metasequoia* differs from *Sequoia* (the redwood of the California coast) by having deciduous rather than evergreen foliage and in having needles that arise opposite one another rather than alternate along the axis. For many years, however, these differences were not recognized, and most specimens from the Bridge Creek flora were identified as *Sequoia. Metasequoia* was first described by Miki (1941), based upon fossils from Japan. Subsequent to Miki's description, living trees of *Metasequoia* were found surviving in central China (Hu and Cheng, 1948). Chaney (1951) reexamined the fossils from Bridge Creek and other western American Tertiary floras and reassigned many to *Metasequoia occidentalis.*

Abies is represented by a cone scale (Figure 2E). *Pinus* is represented by leaves with five needles per fascicle (Figure 2I), occasional seed cones (Figure 2J), pollen cones (Figure 2F), and isolated seeds showing the disarticulation between the seed body and wing (Figures 2G,H). This is the same species that Mason (1927) recorded from Cove Creek and attributed to *P. torreyana.* However, *P. torreyana* is a living species with large, edible seeds unlike those of the fossil. The precise position of this fossil species with respect to living pines remains to be determined.

Only one definite monocotyledonous leaf has been recovered from Fossil (Figure 3A). Although incomplete, it shows parallel venation similar to that of *Canna,* with thick veins alternating with two orders of thinner parallel veins. Most of the other leaves in the assemblage have net-venation typical of dicotyledons.

Mahonia simplex, which belongs to the same genus as Oregon grape, is uncommon in the assemblage but is easily recognized by its asymmetrical, spiny leaflets (Figure 3G). The palmate venation of the leaflets of this fossil species is shared by living Asian species of *Mahonia* and by a single living American species (*M. nervosa;* Schorn, 1966). This species occurs at most localities of the Bridge Creek flora.

Cercidiphyllum (katsura tree), which is presently native to eastern Asia, was first recorded from the Bridge Creek flora by Brown (1935). The leaves, *Cercidiphyllum crenatum* (Figure 3C), are elliptical to ovate with palmate venation and fine glandular teeth. *Cercidiphyllum* fruits (Figure 3D), which appear as clusters of small, slender "pods," are also present at the locality and probably represent the same species as the leaves. However, because a positive link between the fruits and foliage has not been proven by actual attachment, the fruits have been assigned to a separate species for fruits, *C. helveticum* (Jähnichen and others, 1980). These leaves and fruits are essentially identical to those recorded from the Oligocene to Pliocene of Europe (Jähnichen and others, 1980) and are very similar to those of the two modern species. Specimens from the Bridge Creek flora are among the earliest known that correspond precisely to the modern genus. Most of the Paleocene and Eocene remains formerly attributed to *Cercidiphyllum* (Brown, 1939) are now considered to represent related extinct genera (Crane and Stockey, 1985).

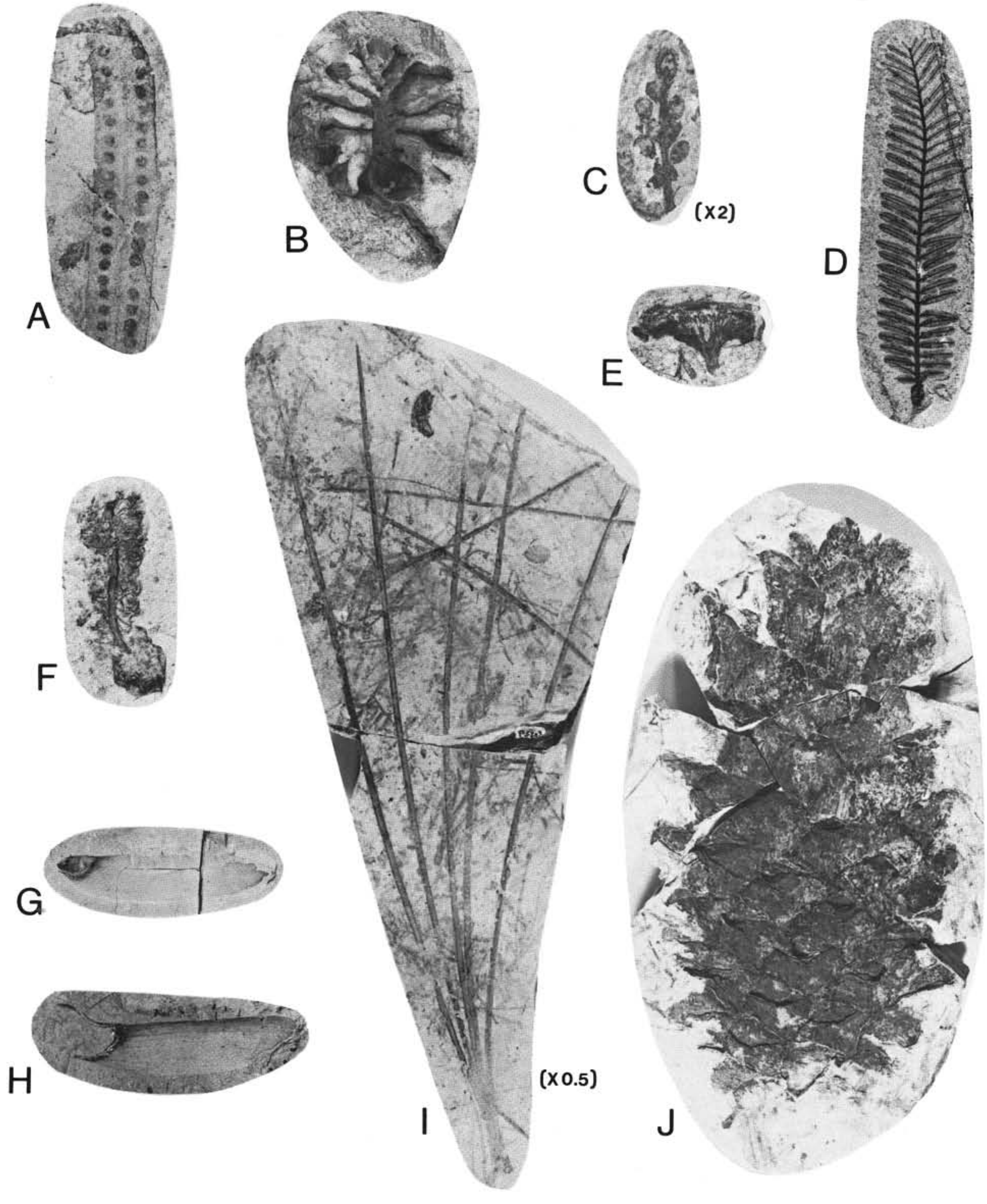

Figure 2. A. Fern pinnule similar to that of Polypodium, *UCMP9310. B.-D.* Metasequoia occidentalis *(dawn redwood). B. Seed cone, IU6988. C. Pollen cone, UCMP9311. D. Branchlet showing opposite arrangement of needles, IU6990. E. Cone scale of* Abies *(fir), IU6991. F.-J.* Pinus *sp. (pine). F. Pollen cone, UCMP9312. G. Winged seed, IU6993. H. Seed showing disarticulation of seed body from wing, IU6994. I. Fascicle of five needles, UCMP9316. J. Seed cone, IU6996.*

The Platanaceae (sycamore family) are represented by two distinct kinds of leaves in the assemblage. Leaves of *Platanus aspera* are common at Fossil and have three broad lobes with numerous prominent teeth, giving the margin a scalloped appearance (Figure 3B). *Platanus aspera* was first recognized from the Bridge Creek locality (Newberry, 1898). Although La Motte (1936) transferred the species to *Tilia,* our specimens show that the species has an inflated petiole base. This and characters of the teeth and venation support Newberry's original assignment. *Platanus condoni* (Figure 3H) includes the largest leaves known from the locality, some measuring up to 40 cm in length. The leaves of this species are fan shaped with five lobes; teeth are infrequent or absent. These leaves are similar in general plan to the leaves of the extinct genus *Macginitiea* (Manchester, 1986; Wolfe and Wehr, 1987), and more detailed study of a larger number of specimens is needed to determine the more appropriate generic position of this species. The Platanaceae are also represented by globose fruiting heads (Figure 3E) and numerous isolated fruitlets (Figure 3F).

Leaves resembling those of *Morus* and *Broussonetia* in the Moraceae (mulberry family) are occasionally recovered (Figure 4A). They are broad and asymmetrical with a finely serrate margin. A pair of strong ascending secondary veins arises from the base of the lamina and gives off evenly spaced tertiary veins that form regular loops near the margin. This kind of leaf has not been reported previously from the Bridge Creek flora.

Two species of the Ulmaceae (elm family) are present, one belonging to a living genus *(Ulmus)* and the other to an extinct genus *(Tremophyllum).* The leaves of *Ulmus pseudo-americana* (elm) are distinguished from other leaves at Fossil by the combination of straight, parallel secondary veins, compound teeth, an asymmetrical base, and a stout petiole (Figure 4B). This species is described in detail from other localities of the Bridge Creek flora by Tanai and Wolfe (1977). Oddly, the distinctive winged fruits of *Ulmus* are not known from Fossil; the only John Day locality from which an elm fruit is known is Gray Ranch. Reexamination of specimens illustrated by Chaney (1927) as fruits of *Ulmus speciosa* and *U. brownellii* indicate that they represent *Pteleaecarpum oregonensis* and an unidentified winged seed, respectively.

Leaves of the extinct genus *Tremophyllum,* formerly described from the Tertiary of Europe (Rüffle, 1963), are relatively narrow and have a stout petiole, an asymmetrical leaf base, and blunt teeth that are distributed one per secondary vein (Figure 4C). These leaves, for which we propose the new name combination *Tremophyllum hesperium* (Brown) comb. nov., are also present at Gray Ranch and were formerly referred to *Ulmus brownellii* (Chaney, 1927) and *Zelkova hesperia* (Brown, 1946). Although correctly placed in the Ulmaceae, this species does not belong to any modern genus (Tanai and Wolfe, 1977, p. 1). Specimens from the Green River and Florissant floras show leaves of this kind attached to twigs bearing fruits of the extinct genus *Cedrelospermum* (Manchester, 1987a). Although such fruits have not been recovered from Fossil, they have been reported from Gray Ranch ("*Banksites lineatus,*" Brown, 1940).

At least three genera of the Juglandaceae (walnut family) are present, although they are not abundant. *Juglans* (walnut) is represented by occasional leaflets and compressed nuts (Figure 4E). Leaflets resembling those of *Pterocarya* (Figure 4D) are also present. Although the distinctive biwinged fruits of *Pterocarya* have not been found at this locality, they are known from the John Day locality at Cant Ranch (Wolfe, 1959). Trilobed winged fruits related to *Engelhardia* occur at several localities of the Bridge Creek flora including Fossil (Figure 4F). Formerly misidentified as *Carpinus* (Chaney, 1927), the species corresponds most closely to *E. olsoni* from the Miocene Latah Formation of Idaho (Brown, 1940; Manchester, 1987b). Similar triwinged fruits occur today in two genera of the Juglandaceae: *Engelhardia* of Asia and *Oreomunnea* of tropical America. In some characters, this fossil species is more similar to *Oreomunnea,* but other characters of the fruits and foliage need to be determined for this fossil species before a positive modern generic assignment can be made (Manchester, 1987b).

The Fagaceae (beech family) are represented by two genera, *Fagus* and *Quercus,* each apparently with one species. *Fagus* (beech) is known from both leaves and nuts at Fossil. The leaves, *Fagus pacifica*

Table 1. *Fossil plant list*

Fern:
cf. *Polypodium* [fertile leaf]

Conifers:
PINACEAE
Pinus sp. [leaves, seed cones, pollen cones]
Abies sp. [cone scales]
TAXODIACEAE
Metasequoia occidentalis (Newberry) Chaney [leaves, seed cones, pollen cones]

Flowering plants:
MONOCOTYLEDONS
Monocotyledonous leaf
DICOTYLEDONS
BERBERIDACEAE
Mahonia simplex (Newberry) Arnold [leaflets]
CERCIDIPHYLLACEAE
Cercidiphyllum crenatum (Heer) Brown [leaf and associated fruits of *Cercidiphyllum helveticum* (Heer) Jähnichen, Mai, and Walther]
PLATANACEAE
Platanus aspera Newberry [leaves]
Platanus condoni (Newberry) Knowlton [leaves]
Platanaceous fruits
MORACEAE
Morus-like leaves
ULMACEAE
Ulmus pseudo-americana Lesquereux [leaves]
Tremophyllum hesperium (Brown) comb. nov. [leaves]
JUGLANDACEA
Juglans sp. [leaflets and fruits]
Pterocarya sp. [leaflets]
cf. *Engelhardia olsoni* Brown [fruit]
FAGACEAE
Quercus consimilis Newberry [leaves]
Fagus pacifica Chaney [leaves and fruits]
BETULACEAE
Alnus hollandiana Jennings emend. Klucking [leaves, catkins]
Asterocarpinus perplexans (Cockerell) Manchester and Crane [fruits and associated leaves of *Paracarpinus chaneyi* Manchester and Crane]
TILIACEAE
"Tilia" circularis (Chaney) comb. nov. [fruits]
Plafkeria obliquifolia (Chaney) Wolfe [leaves]
ROSACEAE
Crataegus newberryi Cockerell [leaves]
cf. *Sorbus* [leaflet]
HYDRANGEACEAE
Hydrangea florissantia Cockerell [flowers]
LEGUMINOSAE
Cladrastis sp. [fruits]
Cercis sp. [fruits]
ACERACEAE
Acer ashwilli Wolfe and Tanai [leaves and fruits]
Acer cranei Wolfe and Tanai [fruits]
Acer manchesteri Wolfe and Tanai [leaves and fruits]
Acer osmonti Knowlton [leaves and fruits]
MELIACEAE
Cedrela merilli (Chaney) Brown [leaf and seed]
INCERTAE SEDIS
Florissantia physalis Knowlton [flower]
Pteleaecarpum oregonensis (Arnold) comb. nov. [fruit]
"Albizzia" ovalicarpa Becker [seed]
cf. *Terminalia* [fruit]
2 unidentified species with serrate leaves
1 unidentified species with entire-margined leaves

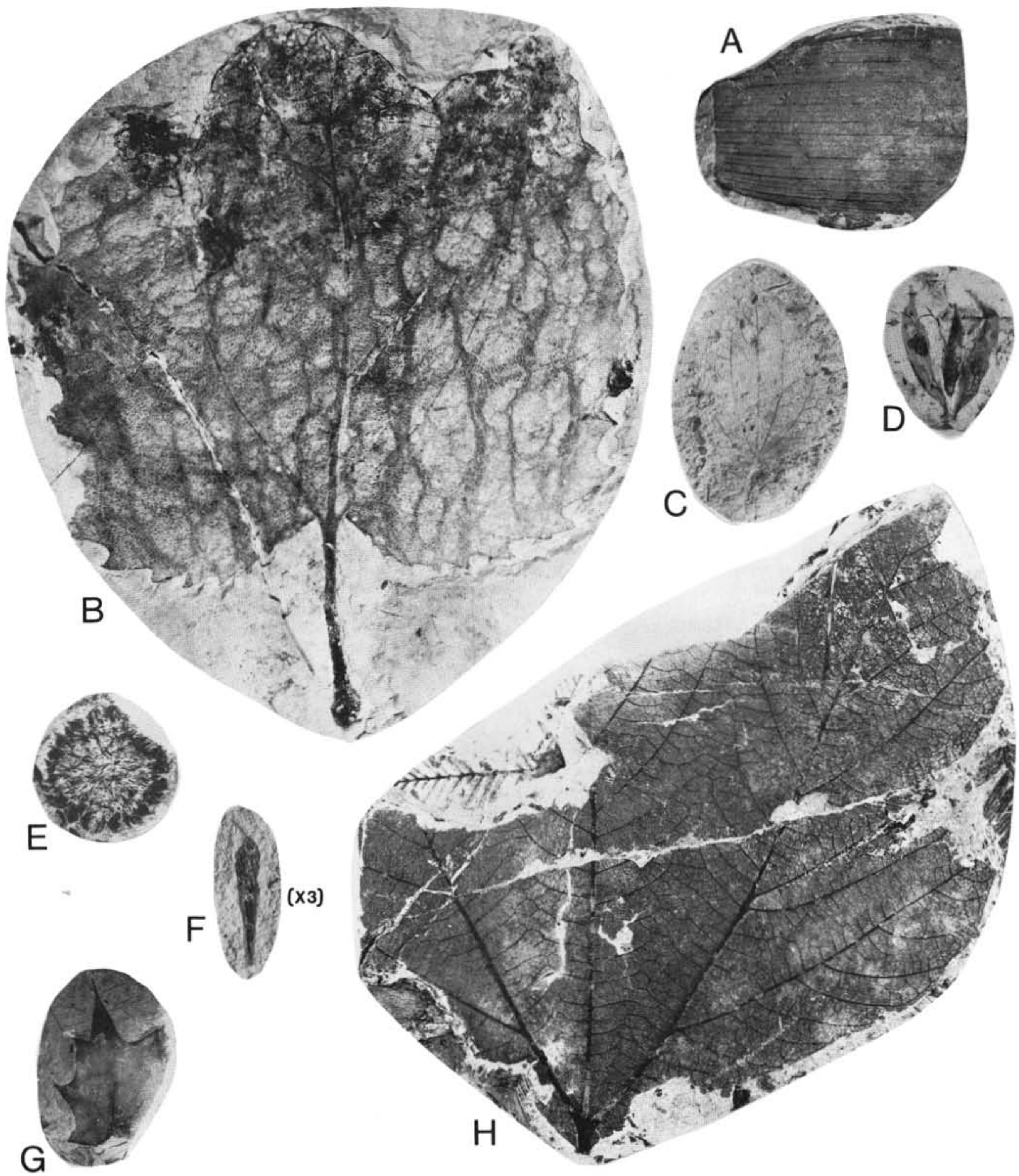

Figure 3. A. Section of a monocot leaf showing parallel venation, UCMP9313. B. Leaf of Platanus aspera *(sycamore), IU6997. C.-D.* Cercidiphyllum *(katsura tree). C. Leaf of* Cercidiphyllum crenatum, *IU7000. D. Three fruits of* Cercidiphyllum helveticum *in cluster, IU7001. E.* Platanus *fruiting head, IU6998. F. Isolated* Platanus *fruitlet, IU6999. G.* Mahonia simplex *(Oregon grape), IU7003. H.* Platanus condoni, *IU7002.*

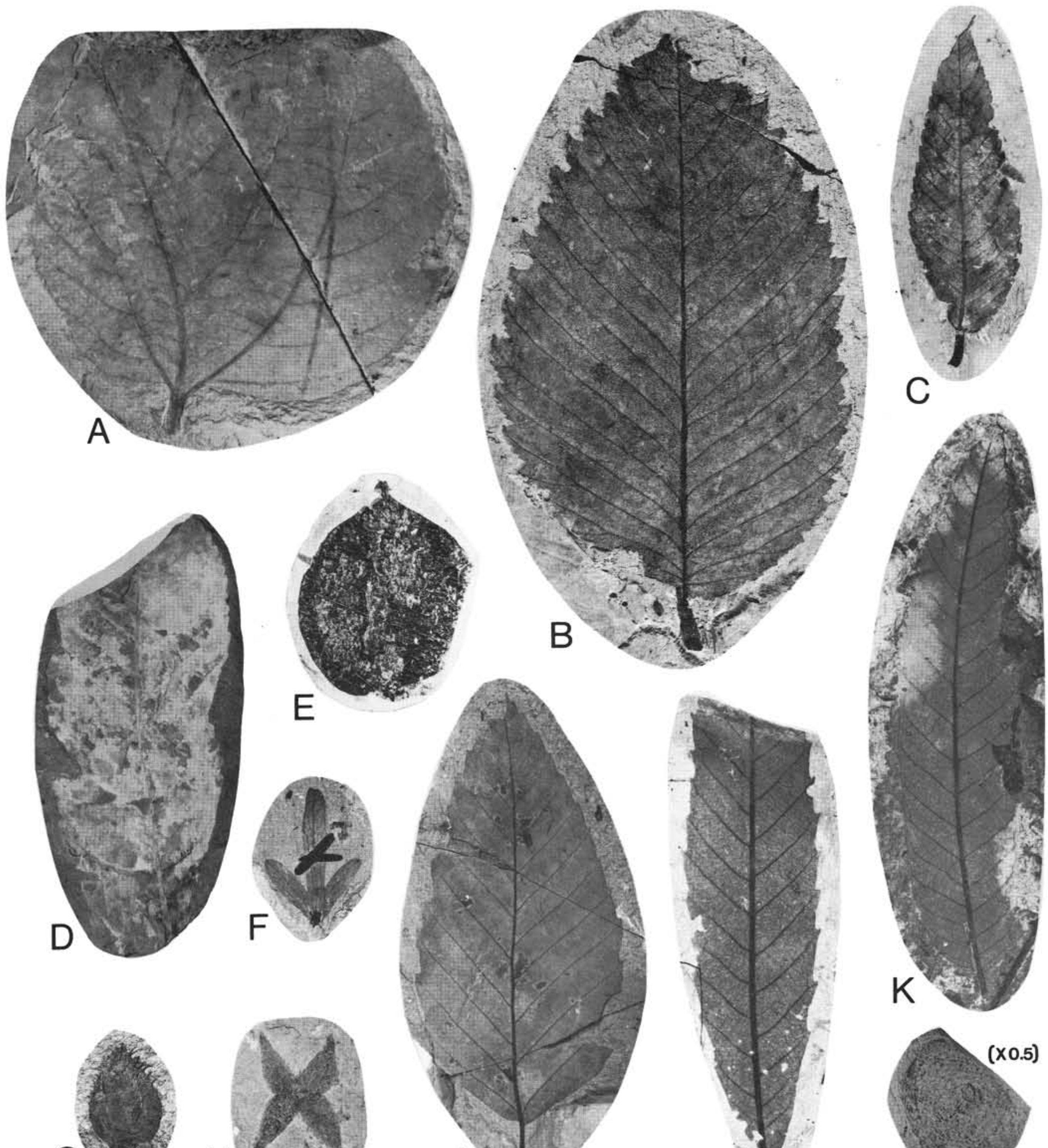

Figure 4. A. Leaf similar to Morus *(mulberry), UCMP9314. B.* Ulmus pseudo-americana *(elm), IU7004. C.* Tremophyllum, *IU7005. D.* Pterocarya, *IU7006. E.* Juglans *(walnut), IU7007. F. Cf.* Engelhardia olsoni, *IU7013. G.* Fagus pacifica *nut (beechnut), showing recurved spines of cupule, IU7008. H. Opened cupule of* Fagus pacifica *showing four valves, IU7009. I. Leaf of* Fagus pacifica *(beech), IU7010. J.* Quercus consimilis *leaf, IU7011. K.* Quercus consimilis *(oak) leaf showing fewer teeth, IU7012. L.* Quercus *cupule (acorn cap), UCMP9317.*

(Chaney, 1927), are ovate with straight parallel secondary veins, each vein entering a tooth at the margin (Figure 4I). The nuts are recognized by their spiny cupule, which may be opened into four valves (Figure 4H) or closed and laterally compressed (Figure 4G). In leaf form (Tanai, 1974), prominence of leaf serrations, and the character of spines on the cupules, this fossil species is very similar to the living species *F. grandifolia* of North America and less similar to the species living today in Europe and Asia.

Leaves of *Quercus consimilis* are long elliptical, with a margin that ranges from fully serrate with a spiny tooth at the terminus of each secondary vein (Figure 4J) to partially serrate with perhaps only a few teeth near the apex (Figure 4K). Based upon the presence of a prominent fimbrial vein along the margin (a character lacking in *Castanea;* Tanai, 1986), the leaves attributed to *Castanea orientalis* by Chaney (1927) from the Gray Ranch and Cant Ranch localities may also belong to *Q. consimilis.* Acorns, although common at Bridge Creek, are rare in the Fossil assemblage. Only two specimens of probable acorn cupules are known, and both are large (approximately 4.5 cm in diameter; Figure 4L).

Leaves of the Betulaceae (birch family) are especially common at Fossil and belong to two genera: *Alnus* and *Paracarpinus. Alnus* (alder) is one of the most abundantly preserved plants in the Bridge Creek flora. Of the three *Alnus* species that Klucking (1959) recognized from Fossil on the basis of leaves, *A. hollandiana* (Figures 5A,B) is particularly abundant at Fossil. The leaves are ovate to elliptical with numerous small blunt teeth and have nonparallel, slightly concave secondary veins. Seed catkins (Figure 5C) and pollen catkins (Figure 5D) are also common.

Leaves and fruits of an extinct genus related to the living *Carpinus* (hornbeam) are also abundant at Fossil. The leaves, *Paracarpinus chaneyi* (Figure 5E; Manchester and Crane, 1987), are elliptical, with numerous small, sharp marginal teeth and straight, parallel secondary veins. The associated fruits, *Asterocarpinus perplexans* (Figure 5F; Manchester and Crane, 1987) consist of a small nutlet surrounded by four, five, or six radiating wings with pinnate venation.

The Tiliaceae (linden tree family) are represented by extinct fruits and leaves at Fossil. Laminae of the kind formerly considered to be leaves of *Asarum* (Chaney, 1927) and *Nymphoides* (Brown, 1946) are abundant at Fossil (Figure 5I), but attached peduncles bearing globose fruits indicate that, rather than leaves, the laminae are fruiting bracts similar to those of modern *Tilia* (linden). Although circular rather than lanceolate, the bracts are remarkably similar in venation to those of modern lindens. The fruits have a basal perianth scar, are five-sided, and have a bumpy surface like those of living *T. petiolaris.* We suggest the new name combination *"Tilia" circularis* (Chaney) comb. nov., indicating the close affinity with this modern genus. However, it is likely that further study will confirm that a new generic name is necessary. Characteristic leaves and lanceolate bracts more similar to those of living species of *Tilia* have not been found at Fossil, although they are present at Cove Creek and Dugout Gulch.

Leaves of *Plafkeria obliquifolia* (Figure 6A) are asymmetrical with entire margins, palmate venation, and a stout petiole. The higher order venation forms a fine orthogonal meshwork. These characters suggest that the leaves may belong to the Tiliaceae (Wolfe, 1977) or Sterculiaceae, and it is possible that these leaves belong either to the plant that produced *"Tilia" circularis* bracts or to that which produced *Florissantia* flowers.

The Rosaceae (rose family) are represented primarily by occasional leaves of *Crataegus* (hawthorn). *Crataegus newberryi* (Figure 5G) occurs at nearly all localities of the John Day and Crooked River basins and was described in detail by Chaney (1927). The leaves are pinnately lobed with small teeth along each lobe. Specimens of prickly stems (Figure 5H) may also belong in the Rosaceae, and a single leaflet resembling *Sorbus* has been observed (Figure 6H). Additional rosaceous genera such as *Rubus, Amelanchier,* and *Rosa* are known from other Bridge Creek localities but have not been identified from Fossil.

Hydrangea, in the Hydrangeaceae, is easily recognized by its flowers with four (rarely three) separate, broad, rounded petals (Figure 5J). It is rare at the Fossil locality and is also present but rare at Gray Ranch, Bridge Creek, and Dugout Gulch. A fruiting panicle of *Hydrangea* from Bridge Creek was illustrated by La Motte (1936, pl. 3, fig. 5; incorrectly identified as *Tilia*).

Two kinds of pods of Leguminosae (pea family) have been recovered from the locality. One of them (Figure 6B) resembles the living *Cercis* (redbud) in having a pod that is winged (having a flange of tissue extending slightly beyond the suture) and in having its seeds oriented perpendicular to the pod. Similar specimens are known from Gray Ranch, Bridge Creek (Chaney, 1927), and Dugout Gulch. The second type of pod (Figure 6C), similar to that of *Cladrastis* (yellow wood), is stipitate, has occasional constrictions between seeds, and has its seeds oriented parallel to its long axis. The specimen described as *Cladrastis oregonensis* by Brown (1937) from Bridge Creek differs from the one figured here in having only one seed and in lacking constrictions. Leaflets similar to *Cladrastis* occur occasionally in the Bridge Creek flora but have not been confirmed at Fossil.

Acer (maple) is common and diverse at most localities of the Bridge Creek flora. Chaney (1927) attributed several leaves and fruits from Gray Ranch to a single species. However, more critical study of the fruits and foliage indicates that eight species are present in the Bridge Creek flora (Wolfe and Tanai, 1987), including four that occur at Fossil: *Acer ashwilli* (Figure 6D), *A. osmonti* (Figure 6F), *A. cranei,* and *A. manchesteri* (Figure 6G).

Cedrela merilli is represented by winged seeds and leaves similar to those of the living *C. mexicana* (Brown, 1937). The characteristic seeds (Figures 6I,J) have thin lateral wings that often show a rounded crease near the distal margin. The leaves (Figure 6K) are recognized by their pronounced asymmetry and smooth margins. *Cedrela* grows today from Mexico to tropical South America. Asian species formerly included in this genus are now placed in a separate genus, *Toona.*

Flowers of *Florissantia physalis* (Knowlton, 1916) are occasionally found at Fossil and are present at most localities of the Bridge Creek flora. The flowers have a large, fused, five-lobed perianth (Figure 6N) and a five-carpeled ovary with a single style. Although previously called *Porana speirii* (Chaney, 1927; Brown, 1940) and more recently *Holskioldia speirii* (MacGinitie, 1953; Brown, 1959), a critical study of the specimens now available from Fossil and Dugout Gulch indicates that they are not related to either of these modern genera and instead are probably flowers of an extinct plant. Some rare specimens show the stamens with large globose anthers (Figure 6-O). The general aspects of this flower suggest that it may belong to the order Malvales.

Pteleaecarpum oregonensis (Figures 6L,M) belongs to an extinct genus of winged fruit that is also known from the Oligocene of Europe (Bůžek, 1971). The species is abundant at Fossil and other localities of the Bridge Creek flora and was formerly identified as *Ulmus speciosa* (Newberry, 1898; Chaney, 1927), *Ptelea miocenica* (Brown, 1937, p. 178, pl. 51, fig. 4), and *Koelreuteria oregonensis* (Arnold, 1952). Unlike *Ulmus* and *Ptelea,* these fruits bear four to six seeds in axile attachment, and unlike *Koelreuteria,* they have small seeds and two rather than three carpels. To our knowledge, *Pteleaecarpum* does not occur in North America except in the John Day Formation.

Unidentified small oval-winged seeds (Figure 6E) are abundant at Fossil and also occur at Dugout Gulch as well as Gray Ranch. These appear to be identical to specimens Becker (1960) described from the Oligocene Mormon Creek flora of southwestern Montana as *Albizzia ovalicarpa,* although the actual generic identity remains undetermined.

Fossil winged fruits resembling those of *Terminalia* are known

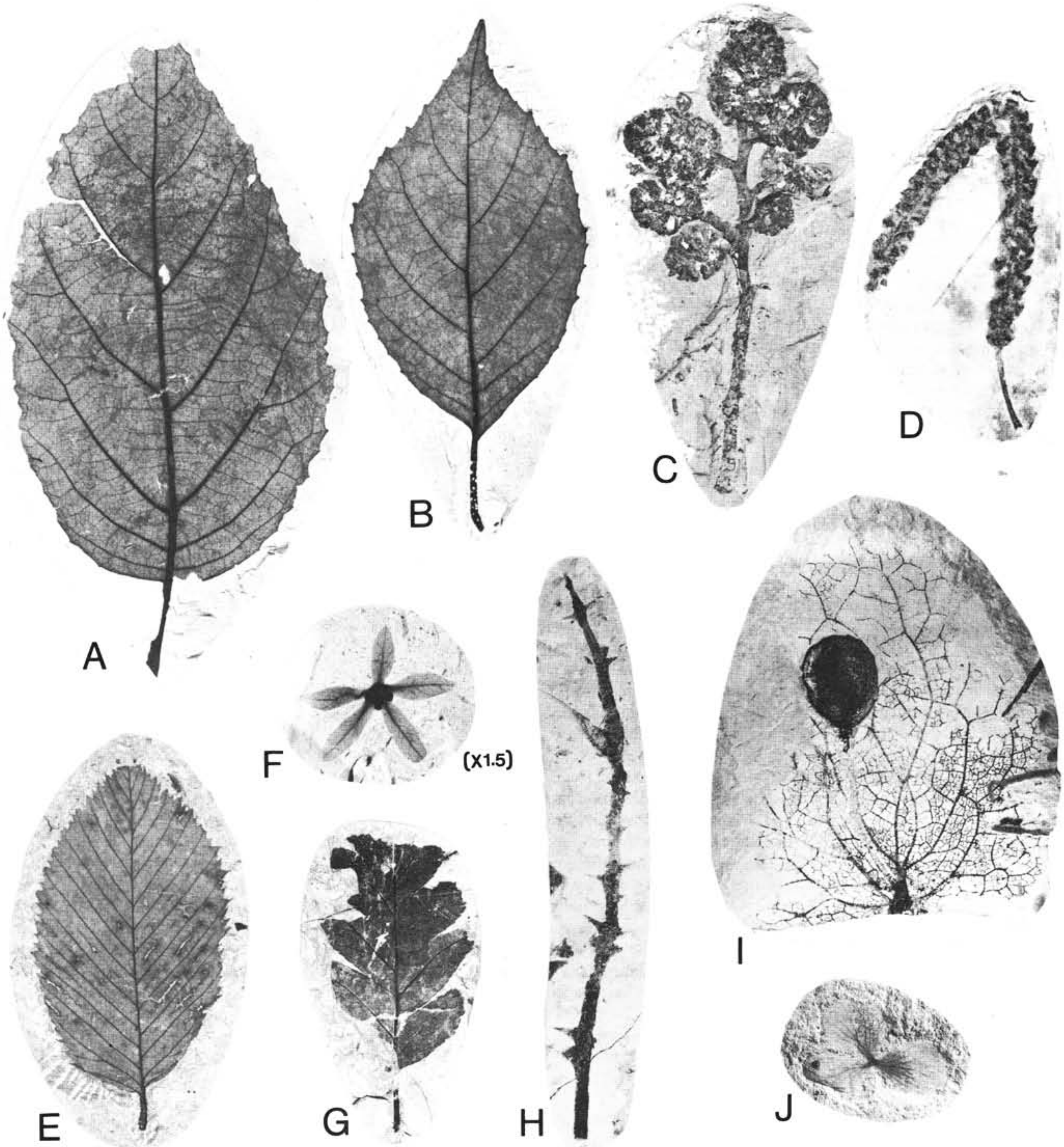

Figure 5. A.,B. Alnus hollandiana *(alder) leaves, IU7014, IU7015. C.* Alnus *seed catkin, IU7016. D.* Alnus *pollen catkin, IU7017. E.* Paracarpinus chaneyi *leaf, IU6098. F. Fruit of* Asterocarpinus perplexans *showing radiating wings, IU6091, 1.5 X. G.* Crataegus newberryi *(hawthorn) leaf, IU7019. H. Prickly stem, IU7020. I. Bract and attached fruit of* "Tilia" circularis *(extinct linden), UCMP9315. J.* Hydrangea *flower, IU7021.*

from two specimens from Fossil, one figured by Brown (1959) and the other here (Figure 6P). They are similar in general outline to the fruits of *Pteleaecarpum* but are distinguished by their larger size and a wing venation that is parallel but not reticulate. The species has not been recovered from other Bridge Creek localities. This kind of winged fruit occurs in several modern families, and the systematic position of this species remains to be confirmed.

EXOTIC AND EXTINCT GENERA OF THE FLORA

Many of the species found at Fossil represent genera that are no longer native to the Pacific Northwest, and some belong to extinct genera. Genera exotic to the present-day flora of the region include *Metasequoia, Cercidiphyllum, Platanus, Ulmus, Pterocarya, Juglans, Engelhardia, Fagus, Hydrangea, Cladrastis, Cercis,* and *Cedrela.* Many occur today in Asia; in particular, *Metasequoia* and

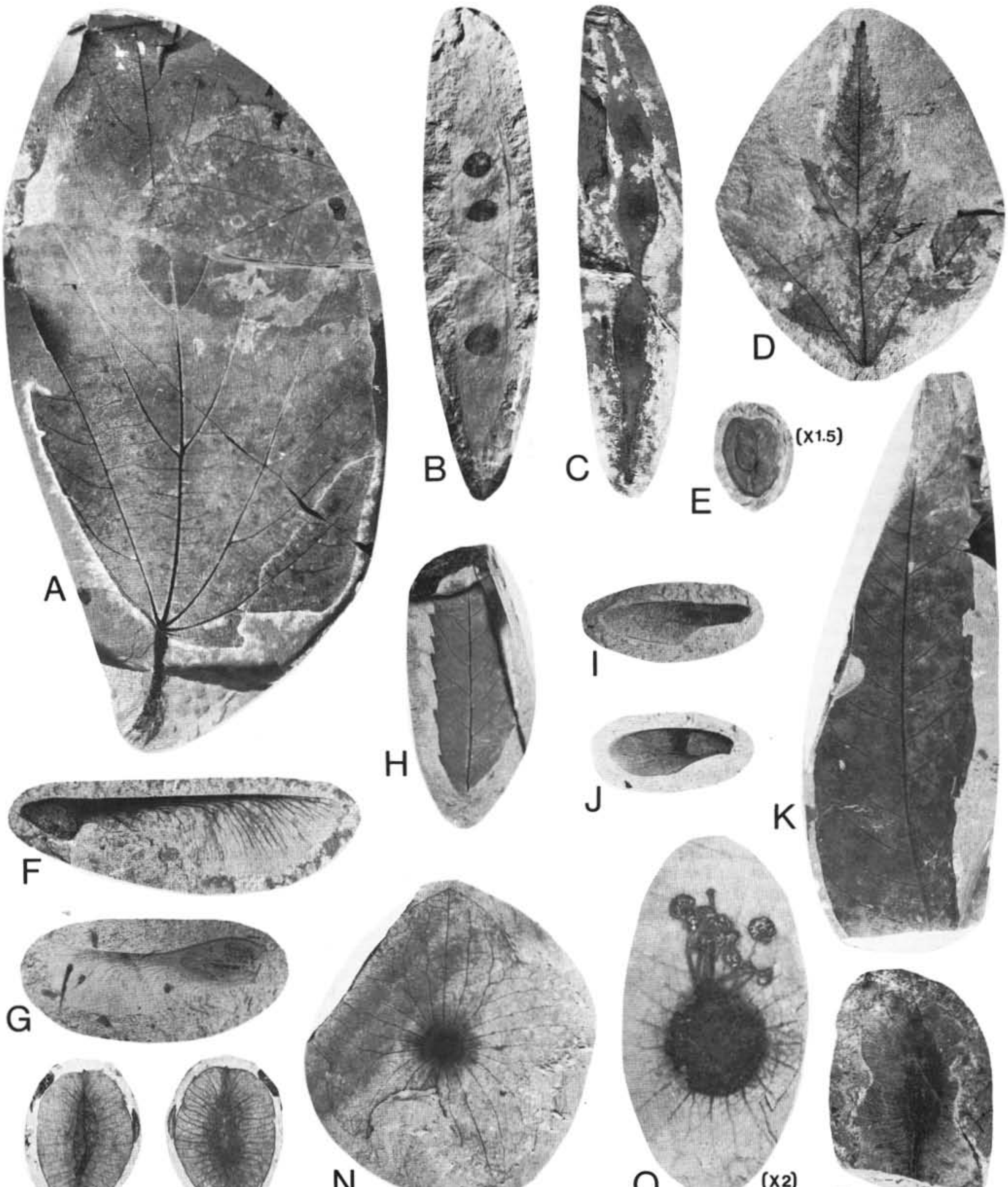

Figure 6. A. Leaf of Plafkeria obliquifolia, *IU7022. B. Pod similar to that of* Cercis *(redbud), IU7023. C. Pod similar to that of* Cladrastis *(yellow wood), IU7024. D. Leaf of* Acer ashwilli *(maple), UCMP 9029. E. Unidentified winged seed, IU7034. F. Winged fruit of* Acer osmonti, *IU7025. G. Winged fruit of* Acer manchesteri, *IU7026. H. Cf.* Sorbus, *IU7027. I.,J. Winged seeds of* Cedrela merilli, *IU7028, IU7029. K. Leaf of* Cedrela merilli, *IU7030. L.,M. Counterpart impressions of a winged fruit* Pteleaecarpum, *IU7033. N.* Florissantia physalis *flower, IU7031. O.* Florissantia physalis *flower with intact stamens, IU7036. P. Winged fruit similar to* Terminalia, *IU7032.*

Cercidiphyllum are presently restricted to eastern Asia, and *Pterocarya* occurs only in eastern Asia and the Caucasus region. The fossil species of *Cedrela* and *Engelhardia* are most similar to those living in Mexico and Central America. *Fagus* is widespread in the Northern Hemisphere today, but the Bridge Creek species is most similar in fruits and foliage to the eastern North American species. Likewise, *Platanus aspera* seems to compare most favorably with the living American species. Most of these genera also occur in Miocene floras of the Pacific Northwest, and their disappearance from this region was probably due to climatic change during the later Tertiary and the Pleistocene.

Previous investigations of the Bridge Creek flora have treated nearly all of the taxa as living genera. However, we estimate that about 15 to 20 percent of the species represent extinct genera. Examples include *Asterocarpinus/Paracarpinus, Tremophyllum, Pteleaecarpum, "Tilia," Plafkeria,* and *Florissantia.* The previous misidentification of these taxa to living genera has resulted in a misleading impression that the Bridge Creek flora was completely modern in its generic composition. The recognition of extinct genera has been aided by more critical study of leaf architecture and by increased attention to associated fruits and flowers.

VEGETATION

One of the most striking aspects noticeable when collecting at this locality is the contrast between the fossil plants and the modern flora and vegetation of this region. The lower elevations around the town of Fossil consist of shrub-steppe and savanna vegetation dominated by grasses, sagebrush *(Artemisia tridentata),* and western juniper *(Juniperus occidentalis),* while the higher, moister elevations in surrounding mountains support coniferous forests with ponderosa pine *(Pinus ponderosa),* Douglas fir *(Pseudotsuga menziesii),* and grand fir *(Abies grandis).* More detailed descriptions of the modern vegetation are provided by Franklin and Dyrness (1973).

Most of the fossil species represent broad-leaved deciduous plants. Conifers are not diverse, although the deciduous foliage of *Metasequoia* is common. Broad-leaved evergreen species also lack diversity and are not common. Most of the species represent tree genera, although *Hydrangea, Mahonia, Crataegus,* and *Sorbus* may have been shrubs. The strong representation of deciduous plants relative to evergreen plants may in part reflect a depositional bias whereby deciduous taxa are overrepresented due to their production of a greater number of leaves that are shed annually. Deciduous taxa are also more common than evergreen taxa as constituents of lakeside and streamside vegetation, resulting in a loss of their leaves directly into or alongside the depositional environment. Nevertheless, evergreen taxa, if present within proximity of the depositional site, should be present in a large collection such as the one from the locality at Fossil, although the abundance of specimens of evergreen taxa may be greatly underrepresented relative to that of deciduous taxa. Similarly low proportions of broad-leaved evergreen taxa are observed at other localities of the John Day Formation, including Knox Ranch, Twickenham, Bridge Creek (Wolfe, 1981), and Dugout Gulch (Manchester and Meyer, unpublished data), although Wolfe (1981) calculated a higher percentage for Post (Gray Ranch).

The assemblage from Fossil, like others of the John Day Formation, indicates vegetation similar to that of temperate hardwood deciduous forests of eastern Asia (Wang, 1961) and eastern North America (Braun, 1950; Vankat, 1979). Most of the Bridge Creek genera no longer occur, however, in the dominantly coniferous forests of the Pacific Northwest. Prior to the discovery of *Metasequoia,* Chaney (1925) compared fossils from the Bridge Creek flora with the living redwood forest of California and incorrectly identified many elements of the flora based upon gross morphology and his preconception that the floras were essentially identical. Later, Chaney (1948a,b, 1952) recognized the similarity of the Bridge Creek flora to modern forests of eastern Asia.

In eastern Asia, broad-leaved deciduous trees dominate several forest types (Wang, 1961; Wolfe, 1979), including the Mixed Mesophytic, Mixed Broad-leaved Deciduous, and Mixed Northern Hardwood forests (sensu Wolfe, 1979). In certain areas, however, the character of some of these forest types was inferred, based on modern vegetation that has been modified by centuries of human activity (Wang, 1961). Based upon physiognomic characters (i.e., those that express the structure and physical appearance of vegetation), such as the relatively low diversity, the proportions of coniferous, broad-leaved deciduous, and broad-leaved evergreen components, the low percentage of entire-margined dicotyledonous leaves (17 percent), and the presence of about 20 percent of species with palmately lobed leaves, the flora from Fossil corresponds most closely to the Mixed Northern Hardwood forest. Wolfe (1981) considered the Bridge Creek flora to represent Mixed Mesophytic forest, although he emphasized (p. 88) that the "reduced broad-leaved evergreen element in these fossil assemblages is anomalous relative to extant vegetation." Physiognomically, the flora is less anomalous in comparison with the Mixed Northern Hardwood forest. With the exception of some species with small leaves, broad-leaved evergreens are generally absent in this modern community (Wang, 1961; Wolfe, 1979). Floristically, the assemblage is more similar to the Mixed Mesophytic forest in the presence of *Cedrela, Cercidiphyllum,* and *Pterocarya.* Most other extant genera of the fossil assemblage occur today in both forest types.

CLIMATIC IMPLICATIONS

It is possible to infer paleoclimatic conditions from fossil floras based upon the climatic distribution of modern vegetation types, which is influenced by temperature, precipitation, and seasonality. Wolfe (1979) plotted the temperature parameters for different vegetation types in eastern Asia and showed that the Mixed Northern Hardwood forest occurs in mesic areas where the mean annual temperature ranges from 3 to 10 °C, the mean cold month temperature ranges up to -2 °C, the mean warm month temperature ranges from 20 to 28 °C, and the mean annual range of temperature (i.e., a measure of equability, given as the difference between mean warm month temperature and mean cold month temperature) ranges from 23 to 45 °C. The Mixed Mesophytic forest of China, however, occupies a narrower range of temperature parameters, with the mean annual temperature ranging from 9 to 13 °C, the mean cold month temperature from -2 to 1 °C, the mean warm month temperature from 20 to 27 °C, and the mean annual range of temperature from 20 to 29 °C.

Wolfe (1981) pointed out that the occurrence of large-leaved (greater than 20 cm^2) broad-leaved evergreen species is significant in assessing paleoclimate, because these species are generally limited to vegetation of climates where the mean cold month temperature is greater than -2 °C. The apparent lack of such species in the assemblage from Fossil indicates that the mean cold month temperature may have been less than -2 °C. Although *Mahonia* is an evergreen, its leaflets are small, and some living species of this genus extend into cold vegetation where large-leaved broad-leaved evergreens are absent. *Engelhardia* and *Cedrela* include modern species that are broad-leaved evergreens, but both also include living species that are deciduous. Thus, it cannot be assumed that the fossil species of these genera were evergreens. *Engelhardia* is known in the assemblage only from fruiting material; however, the leaves of *Cedrela* were apparently deciduous, judging from their thin textures.

Leaf-margin percentages provide another criterion for comparison of floras of different climates. Bailey and Sinnott (1915) observed a correlation in living vegetation between the percentage of species having entire-margined leaves (i.e., leaves that lack teeth or lobes) and climate, with successively higher percentages of entire-margined leaves in cool temperate, warm temperate, and lowland tropical floras. Further studies have shown that the percentage is influenced by mean annual temperature (Wolfe and Hopkins, 1967; Wolfe, 1971) as well as rainfall (Dilcher, 1973). Wolfe (1979) indicated a direct correlation between mean annual temperature and leaf-margin percentage in mesic climates, based upon undocumented data from eastern Asia, although a much less precise correlation was found in well-documented studies of the Carolinas (Dolph and Dilcher, 1979) and Costa Rica (Dolph, 1979). We estimate that the Fossil assemblage has 17 percent entire-margined leaves; this figure is based upon 28 dicot species and includes margins inferred for leaves of three extant genera presently represented only by fruits (*Hydrangea*, serrate; *Cladrastis* and *Cercis*, entire). Using the simple correlation between leaf margin and mean annual temperature as proposed by Wolfe (1979), this value corresponds to a mean annual temperature of about 5 °C. Our leaf-margin percentage is lower than that published previously for the Bridge Creek flora (25 percent, based upon 66 species from several localities; Wolfe and Hopkins, 1967; Wolfe, 1971) and that calculated for Gray Ranch (34 percent entire margins, based upon 37 species; Wolfe, 1981) and Dugout Gulch (24 percent entire margins, based upon 25 species; Manchester, unpublished data). It is possible that the assemblage from Fossil varies somewhat from other Bridge Creek localities (particularly Gray Ranch) due to differences in age, altitude, successional stage, or factors of local ecology.

Fossil floras of similar age from the Western Cascades of Oregon, such as the Lyons (Meyer, 1973) and Rujada (Lakhanpal, 1958) floras, contain more conifers and broad-leaved evergreen taxa than the Bridge Creek flora. Wolfe (1981) considered these more coastal floras to represent Broad-leaved Evergreen and Coniferous forest, suggesting that the climate nearer the Oregon coast (then in the area of the present Willamette Valley) may have had a slightly warmer mean annual temperature and a slightly lower mean annual range of temperature (i.e., more equable) than the inland area occupied by the Bridge Creek flora. Compared with the present climate of western Oregon, the Lyons and Rujada floras indicate that the mean annual temperature has apparently not changed significantly, although the mean annual range of temperature has decreased about 5 to 10 °C (i.e., summers have become cooler, and winters are warmer) (Wolfe, 1981). The present climate of Oregon also differs in having reduced summer precipitation. Aridity is particularly pronounced today in central and eastern Oregon and can be attributed to the rain-shadow effects resulting from the late Cenozoic development of the High Cascades.

Vegetational analyses and leaf-margin data from a number of western Tertiary floras (Wolfe and Hopkins, 1967; Wolfe, 1978) reveal that the most striking climatic event of the Tertiary was a drastic (about 10 to 11 °C) decline in mean annual temperature along with an increase of about 15 to 16 °C in mean annual range of temperature (at middle latitudes) that occurred during the Oligocene between about 32 and 34 m.y. ago, just prior to the deposition of the Bridge Creek flora (Wolfe, 1978). In the John Day basin, the Eocene Clarno Formation contains fossil leaf assemblages that represent warmer, more equable climatic conditions than the Bridge Creek flora. The Clarno Nut Beds assemblage (Manchester, 1981) is much more diverse than the Bridge Creek flora, includes many broad-leaved evergreen taxa that are primarily restricted to tropical and subtropical areas, and, based on physiognomic criteria, probably had a mean annual temperature of more than 20 °C. Following the Oligocene climatic change, temperate climate persisted in lowland areas with only moderate fluctuations through the remainder of the Tertiary (Wolfe, 1978).

ORIGIN OF THE FLORA

A comparison of the Bridge Creek flora with older floras in the region such as the Clarno raises questions concerning the mechanism of floral change through which hardwood deciduous forests replaced near-tropical vegetation during the Oligocene. The Arcto-Tertiary geoflora concept, a theory that developed as early as the late 1800's and was later expounded upon by Chaney (1938, 1940, 1947, 1948a), sought to explain this change and became widely accepted as fact. Wolfe (1977) presented the most complete historical review of this concept but also provided new evidence discrediting the theory. The Arcto-Tertiary concept basically maintained that a temperate, broad-leaved, deciduous forest having a definite floristic composition evolved in high northern latitudes during the Cretaceous and early Tertiary and "migrated" southward to middle latitudes during the Oligocene as a response to gradual climatic cooling. Although Chaney (1948b, p. 21-22) noted that some species failed to survive while others were added during this "migration," he believed that the Arcto-Tertiary geoflora underwent little floristic change and maintained its general character over a wide interval of time and space.

Mason (1947) was the first to challenge the theoretical basis for the Arcto-Tertiary geoflora by pointing out that such stability and unity of plant communities through time and space were not possible in view of the dynamic interaction between population genetics, physiological tolerances of individual species, and the fluctuation of the environment. During an event of climatic or environmental change, each individual plant species will have its own unique genetic capability of coping with such a change; it is not conceivable that all species within a plant community will have the same response. To assume that the floristic composition of a plant community remains fundamentally unchanged over a long interval of time is inconsistent with evolutionary theory. Based upon studies of Alaskan Tertiary floras, Wolfe (1972, 1977) disputed the fossil and stratigraphic evidence for the Arcto-Tertiary concept by showing that the high-latitude Eocene to early Oligocene floras of Alaska were subtropical to near-tropical, similar to middle-latitude floras of the same age from the Pacific Northwest, and lacked the floristic and vegetational character assumed by Chaney.

The Mixed Mesophytic and Mixed Northern Hardwood forests began developing during the Oligocene from lineages having origins in older floras of dissimilar character. Based upon the studies and ideas of Mason (1947) and Wolfe (1972, 1977), plant species can be envisioned as having had at least four possible responses to the Oligocene climatic cooling: (1) extinction, (2) survival through preadaptation, (3) survival through rapid evolution, and (4) dispersal from upland regions. Many species that inhabited the Eocene and early Oligocene near-tropical forests of the Pacific Northwest became extinct during the rapid Oligocene climatic deterioration, but some species may have had physiological tolerances that would have allowed them to live under cooler, less equable climatic conditions, or such tolerances may have evolved rapidly to accommodate climatic change. For example, genera such as *Pterocarya, Plafkeria, Engelhardia, and Platanus* are known from the older, warmer floras from this region, but apparently survived the climatic change to become members of the plant community represented by the Bridge Creek flora. Other taxa in the Bridge Creek flora were closely related to those from older upland floras (Wolfe, 1972), where temperatures were cooler than in the lowlands, and some lineages may have dispersed from these upland areas into lowland areas during the climatic change. Bridge Creek taxa such as *Abies, Acer, Crataegus, Mahonia,* and *Asterocarpinus* also occur in somewhat older upland floras from the Rocky Mountain region, such as the Florissant (MacGinitie, 1953), Ruby (Becker, 1961), and Red Rock Ranch and Marshall Pass (Meyer, 1986) floras, suggesting probable upland sources for these taxa. Some taxa (e.g., *Tremophyllum, Florissantia,* and *Hydrangea*) occur in both the temperate upland and near-tropical lowland floras of the Eocene to early Oligocene; their occurrence in the Bridge Creek flora may have resulted from either source.

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USGS releases new-style topographic map index and catalog for Oregon

A new index and a companion catalog of the 3,764 topographic and related maps of Oregon available from the U.S. Geological Survey (USGS) have been published by the USGS, the nation's principal civilian mapping agency.

The "Oregon Index to Topographic and Other Map Coverage" and the "Oregon Catalog of Topographic and Other Published Maps" were designed to assist users in selecting and purchasing maps of the state.

Both index and catalog are in booklet form. They replace the old single-sheet index and are the first of their kind for Oregon. A program to issue similar publications for all 50 states will be completed soon.

"For the first time, all topographic and related USGS maps of Oregon are included in one easy-to-use index and catalog set, " said John R. Swinnerton, Menlo Park, Calif., chief of the Western Mapping Center of the Survey's National Mapping Division. "These include planimetric, topographic, and photo-image maps, as well as land-use and land-cover maps. The old-style index did not show or list all of the 37 different USGS map products currently available to the public."

The new Oregon index and catalog also list United States maps, county maps, national park maps, National Atlas maps, world maps, orthophotoquads, orthophotomaps, and special maps that include all or parts of Oregon.

"The new indexes do not have to be updated and published periodically, but the catalogs will be efficiently and economically updated by computer and reissued as needed," Swinnerton said. Previously, the updating and reprinting process took several years.

The Oregon catalog contains forms for ordering topographic and other maps from the USGS. The catalog also lists 54 private map dealers in Oregon who sell USGS maps and the 15 libraries in Oregon that have the maps for reference and inspection.

Single copies of the new Oregon index and catalog are available free of charge from the U.S. Geological Survey, Map Distribution, Box 25286, Federal Center, Denver, Colo., 80225, telephone (303) 236-7477. Copies also can be obtained from authorized USGS map dealers listed in the catalog or in local telephone yellow pages under "Maps." □

Oregon Agate and Mineral Society display featured at State Capitol

On September 15, 1987, Wally and Jean Hobson of the Mount Hood Rock Club of Gresham removed their display from the Oregon Council of Rock and Mineral Clubs display case at the Capitol Building in Salem. They plan to keep it intact to exhibit at their annual show and also at the Portland Regional Show, October 23-25th.

On the following day, the Oregon Agate and Mineral Society (OAMS) of Portland installed its colorful exhibit featuring sagenite, moss and plume agate and Oregon sunstones. Lighted frames at each end of the 11-ft case displayed sagenite agate, while transparent specimens were placed on the bottom shelf to take advantage of the fluorescent lighting underneath.

Featured in the display was the framed proclamation, signed by Governor Neil Goldschmidt, on August 4th, 1987, making the Oregon sunstone the official Oregon gemstone. Also displayed were faceted and tumbled sunstones, some colored rough specimens, and a 100-carat shaped and polished sunstone pendant.

Several OAMS members contributed the more than 40 items, representing 15 Oregon counties, shown in the display. Ray Schneider, charter member of OAMS, President Chuck Sweany, and Evelyn Sweany arranged the exhibit, assisted by Lyle Riggs, Agent for the Council.

The display will remain until January 15, 1988, and will be followed by an exhibit provided by the Roxy Ann Gem and Mineral Club of Medford, Oregon. □

USGS publishes Professional Paper on the geology of the Blue Mountains region

The U.S. Geological Survey (USGS) has released the first of several professional papers focusing on the geology, paleontology, and mineral resources of eastern Oregon, western Idaho, and southeastern Washington. Entitled *Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Geologic Implications of Paleozoic and Mesozoic Paleontology and Biostratigraphy, Blue Mountains Province, Oregon and Idaho,* Professional Paper 1435 was edited by Tracy L. Vallier, USGS, and Howard C. Brooks, Baker Field Office, Oregon Department of Geology and Mineral Industries.

As stated in the preface of the paper, the purpose of this series is "to familiarize readers with the work that has been completed in the Blue Mountains region and to emphasize the region's importance for understanding island-arc processes and the accretion of an allochthonous terrane. These professional papers provide current interpretations of a complex island-arc terrane that was accreted to ancient North America in the late Mesozoic Era, of a large batholith that was intruded after accretion had occurred, and of overlying Cenozoic volcanic rocks that were subsequently uplifted and partly stripped off the older rocks by erosion."

This volume contains seven papers on the biostratigraphy of pre-Tertiary rocks in the Blue Mountains, plus a review of the implications of the faunal data. The titles of the papers and their authors are as follows:

1. Paleozoic and Mesozoic faunas of the Blue Mountains province: A review of their geologic implications and comments on papers in the volume; by Tracy L. Vallier and Howard C. Brooks.
2. Late Triassic bivalves of the Martin Bridge Limestone, Hells Canyon, Oregon: Taphonomy, paleoecology, and paleozoogeography; by Cathryn R. Newton.
3. Late Triassic coelenterate faunas of western Idaho and northeastern Oregon: Implications for biostratigraphy and paleogeography; by George D. Stanley, Jr.
4. A Norian (Late Triassic) ichthyosaur from the Martin Bridge Limestone, Wallowa Mountains, Oregon; by William N. Orr.
5. Jurassic ammonites and biostratigraphy of eastern Oregon and western Idaho; by Ralph W. Imlay.
6. Conodont ages for limestones of eastern Oregon and their implication for pre-Tertiary melange terranes; by Ellen Mullen Morris and Bruce R. Wardlaw.
7. Faunal affinities and tectonogenesis of Mesozoic rocks in the Blue Mountains province of eastern Oregon and western Idaho; by Emile A. Pessagno, Jr., and Charles D. Blome.
8. Geologic implications of radiolarian-bearing Paleozoic and Mesozoic rocks from the Blue Mountains province, eastern Oregon; by Charles D. Blome, David L. Jones, Benita L. Murchey, and Margaret Liniecki.

More professional papers on the same area will appear over the next few years. Copies of Professional Paper 1435, which is 93 pages long, may be purchased directly from the USGS, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. Cost of the publication is $5.50. □

Open-file reports available

This is just a reminder to you that the Oregon Department of Geology and Mineral Industries (DOGAMI) has approximately 70 of its open-file reports available for purchase and another 20 that are out of print but available for in-library use.

Please feel free to request a copy of the list of open-file reports from the DOGAMI Portland office. □

GSA publishes Cordilleran field trip guides

The Geological Society of America (GSA) has just released the first of the Centennial Field Guide Volumes in its *Decade of North American Geology (DNAG) Project* series. Edited by Mason L. Hill and entitled *Cordilleran Section of the Geological Society of America,* the 490-page book contains field trip guides to Hawaii, Arizona, Nevada, California, Oregon, Washington, British Columbia, and Alaska.

Oregon field trip guides and their authors are as follows:

1. Shelf and marine deposits of Late Cretaceous age, Cape Sebastian area, southwest Oregon; by Ralph E. Hunter and H. Edward Clifton.
2. Mount Mazama and Crater Lake caldera; by Charles R. Bacon.
3. Depoe Bay, Oregon; by Parke D. Snavely, Jr.
4. Late High Cascade volcanism from the summit of McKenzie Pass, Oregon: Pleistocene composite cones on platform of shield volcanoes: Holocene eruptive centers and lava fields; by Edward M. Taylor.
5. Record of early High Cascade volcanism at Cove Palisades, Oregon: Deschutes Formation volcanic and sedimentary rocks; by Edward M. Taylor and Gary A. Smith.
6. John Day Fossil Beds National Monument, Oregon: Painted Hills unit; by Paul T. Robinson.
7. Columbia River Gorge: The geologic evolution of the Columbia River in northwestern Oregon and southwestern Washington; by Marvin H. Beeson and Terry L. Tolan.
8. The Wallowa Mountains, northeast Oregon; by William H. Taubeneck.

The book, which costs $43.50, may be ordered directly from GSA, PO Box 9140, Boulder, CO 80301. □

Oregon sunstone proclaimed Oregon's official State Gemstone

The Oregon sunstone has been made the official State Gemstone by proclamation of Governor Neil Goldschmidt and by a Joint Resolution of the Oregon Legislative Assembly. The Governor's Proclamation was signed on August 4, 1987.

Oregon sunstones, a gem variety of the feldspar mineral group, occur in Lake and Harney Counties, where they are dug from the soil and the underlying lava flows. Feldspars generally occur in a large variety of rock types, usually as small crystals that are typically opaque with rather dull colors of white or gray; Oregon sunstones, however, are large, brightly colored, transparent, gem feldspars. Sunstone crystals as large as 3 in. have been found, and the gems range in color from water clear through pale yellow, soft pink, and blood red to deep blue and green. Some of the deeper colored stones have bands of varying color; a few stones show two different colors when viewed from different directions. Many sunstones appear to be perfectly transparent, but when viewed in just the right direction, a pink to red metallic shimmer flashes from within the stone as a collection of small spots or as a mirrorlike surface. The color variations and the shimmer apparently are caused by different amounts and sizes of tiny crystals of copper metal within the stones.

Sunstones from eastern Lake County, near Plush, have been prized by collectors for many years, and a free public collecting area has been established by the U.S. Bureau of Land Management District Office in Lakeview. The recent discovery of two more occurrences in northern and southeastern Harney County has permitted mining of an increased amount of marketable gem material, and the geology of the area is favorable for the discovery of additional deposits. The economic effects of sunstone collecting and mining include tourism and the sales of rough material, cut gems, and finished jewelry.

The retail value of cut sunstones currently ranges from $15 to over $100 per carat, with higher prices received for red, blue, or green colors, for larger or clearer stones, and for more elaborate cuts. A one-carat sunstone in a traditional round brilliant cut would be about the size of a pencil eraser. Oregon sunstones are uncommon in their composition, clarity, and range of colors, and they occur in sufficient abundance to permit sustained production of faceted gems. □

Correction

The article "Mercury and uranium mineralization in the Clarno and John Day Formations" in the September issue began with a slightly incorrect statement: The first line of the first sentence of the introduction contained a superfluous "the" and lacked two commas. The correct sentence should have read: "Occurrences of precious metals, mercury, and uranium have been reported from the Eocene to Oligocene Clarno Formation in the Ochoco and Blue Mountains."

We apologize for this error. —*Editor*

Give us your opinion

We are considering publishing *Oregon Geology* every two months, rather than every month as we currently do. The cost of subscriptions and total number of pages published each year would remain the same, but the frequency of publication would be cut in half. This change would mean that each of the six issues per year would be twice as long, which would enable us to have more variety and longer articles in each issue.

We would like to know what you think about this contemplated change before the end of the month. Please mark the questionnaire below and add any comments.

_____ 1. Good ideas! I see lots of possibilities.
_____ 2. Seems reasonable.
_____ 3. Doesn't matter to me.
_____ 4. Poor idea.
_____ 5. Terrible idea. I do not like it at all.

Comments: ________________________________

____

____

Name (optional) ________________________________

Send to Beverly Vogt, Oregon Department of Geology and Mineral Industries, 910 State Office Building, Portland, OR 97201. □

Glimpses of DOGAMI history — field travel 44 years ago

The photographs were taken during field work in Malheur County in 1943. Some areas near the Owyhee Reservoir were explored for clear calcite crystals ("Iceland spar")—a strategic commodity used in optical instruments such as bomb sights. Leading Department staff members in the field were then field geologist N.S. Wagner and then engineer R.S. Mason; the final report published in the June 1943 issue of *The Ore-Bin* was written by then junior geologist W.D. Lowry.

The Department vehicle (Ford V-8 panel truck) shows the name of the Department on the door panel and a message on the side panel: "Boost Oregon Mineral Production."

Certain traveling casualties were to be expected, judging from examples of how access to the calcite deposits was described:

"Distance from the property to Dry Creek is 4.8 miles, the road, for the most part, being the creek bed. Distance from Dry Creek to Twin Springs is 4 miles, over rough, highly washed road. Distance from Twin Springs to Vale-Burns highway [is] 26 miles over fair

desert road" (N.S. Wagner, initial report, April 1943).

Or, in another case: "The property may also be reached from Nyssa by road to Adrian (13 miles) and thence south by road 15 miles up the Sucker Creek road. An old and possibly impassable road leads west to Board Corral Spring (±15 miles) and then west about 4 miles to within 2 miles of the property. The claim is then 2 miles north. There is no trail" (W.D. Lowry, initial report, July 1943).

Nowadays, of course, such problems are not supposed to occur any more . . . □

Oregon rock sent to Philadelphia to honor U.S. Constitution

During the fourth week of September 1987, a three-ton boulder of Lake County basalt was shipped from Portland to Pennsylvania, where, after trimming and polishing, it will be placed with rocks from the other 49 states in Constitution Wall in Philadelphia's Independence National Historic Park. The wall, which will be bordered by the Liberty Bell and Independence Hall, commemorates the bicentennial of the U.S. Constitution.

The Oregon rock was selected by Jerry J. Gray, Economic Geologist, Oregon Department of Geology and Mineral Industries, because it was unjointed, unflawed, and large enough to be trimmed into a block for the wall—and because it contained numerous sunstones, Oregon's newly proclaimed gemstone.

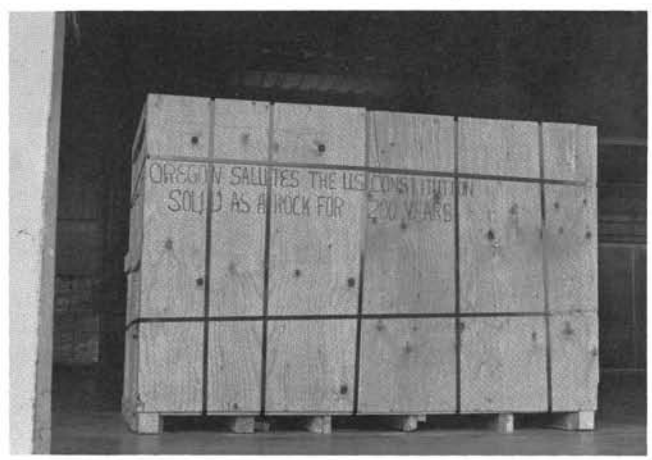
The rock, which originally weighed eight tons, was transported from a private mining claim on Bureau of Land Management (BLM) land in Lake County by Oregon Highway Division personnel supervised by Gordon McCoy to a maintenance shop in Adel, where it was laboriously shaved by a hydraulic impact hammer down to three tons. Then the Highway Division trucked it to Elite Granite and Marble Company in Hillsboro, who crated and prepared it for shipping. Finally it was shipped by truck to Philadelphia, courtesy of Chet Lowrey, owner of Keith's Terminals of Portland.

Basalt boulder, at its original location on a private mining claim on BLM land in Lake County.

First attempts to load the boulder onto a truck were unsuccessful because the rock was too heavy. Note men trying to provide a counterweight at the back of the loader. Eventually the stone was pushed onto the truck.

The boulder was eventually shaved to a smaller size by a hydraulic impact hammer mounted on an excavator.

Final shape of the basalt rock before it was crated up for shipment. Note vertical stripes from hydraulic impact hammer.



Oregon's basalt rock, ready for shipment to Philadelphia.

When the stone reaches its destination, it will be sawed and polished into a 2-ft by 2-ft by 4-ft block and inscribed with the words "Oregon" and "February 14, 1859," the date Oregon entered the Union. Then it will be cemented into the wall, symbolizing the fact that President James Madison, author of the Constitution, once called the Constitution "the cement of the Union." □

AVAILABLE DEPARTMENT PUBLICATIONS

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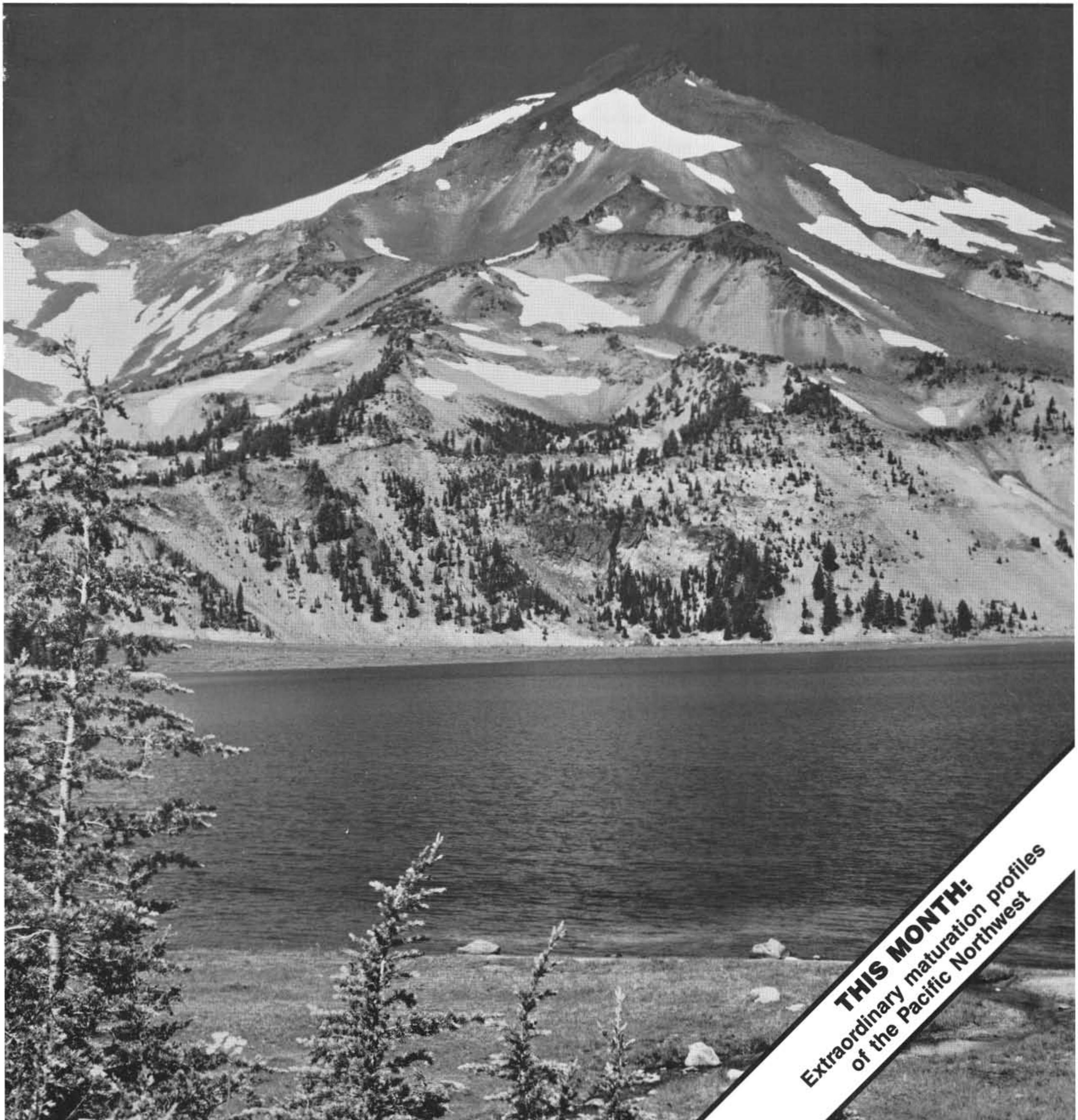

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

South Sister, one of the Cascade volcanoes, as seen looking west across the Green Lakes basin. Article beginning on next page suggests that thermal fluids associated with this type of volcanism may have assisted in the maturation of sedimentary units with respect to oil and gas generation throughout the Pacific Northwest. Photo courtesy Oregon State Highway Division.

OIL AND GAS NEWS

ARCO remains active at Mist

ARCO has drilled the Columbia County 31-27-65 well to a total depth of 6,700 ft, which makes it a relatively rare test of the deeper sediments at Mist. Production casing was run on the well to a depth of 1,690 ft, and the well is currently suspended, awaiting completion. ARCO next drilled the Columbia County 31-34-65 well to a depth of 2,344 ft and has run production casing, and the well also is currently suspended, awaiting completion. ARCO is planning completion tests on both wells.

ARCO is currently drilling the Columbia County 34-4-65 well, the fifth well of ARCO's 1987 drilling program at Mist.

Damon plans conversion to water well

Damon Petroleum plans to convert its Stauffer Farms 35-1 well in Marion County to a water well. This well was abandoned in September 1987 after an unsuccessful attempt to reenter and deepen it. The well was erroneously listed in the October issue of *Oregon Geology* under permit number 397; the correct permit number is 358D. □

Republic, Wash., opens new fossil center

The town of Republic, Washington, hosted an open house at its new Stonerose Interpretive Center on August 18, 1987. Over 70 people attended the opening of this addition to the Republic town parks.

The Stonerose Interpretive Center is a small museum that houses a representative group of middle Eocene plant fossils and a few excellently preserved fish and insect fossils from the same strata as the Republic fossil flora. The Center is located adjacent to a major collecting site of the fossils it displays.

Important collections have been made here for a decade by Wes Wehr, Affiliate Curator of Paleobotany at the Burke Museum at the University of Washington, also by Kirk Johnson and Michael Spitz, with the help of several interested citizens of Republic. Wehr and Jack A. Wolfe, U.S. Geological Survey (USGS), recently completed a study of the Republic flora and published it in USGS Bulletin 1597 (1987).

Madilane Perry, Curator of the Stonerose Interpretive Center, explained that the town's recent acquisition of the fossil site was a major stimulus to create the Interpretive Center. She hopes the Center will bring a new attraction to this town of former gold-mining glory.

From November 20 until (probably) mid-May, the Center will be closed. However, Curator Perry will answer mail inquiries. For more information, contact Madilane Perry, Stonerose Interpretive Center, P.O. Box 987, Republic, WA 99166, phone (509) 775-2295; or the Republic Town Hall office, phone (509) 775-3216.

—Melvin S. Ashwill, Madras

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Beverly F. Vogt, Publications Manager

Extraordinary maturation profiles of the Pacific Northwest

by Neil S. Summer, Department of Geology, Hebrew University, Jerusalem, Israel; and Kenneth L. Verosub, Geology Department, University of California, Davis, CA 95616

ABSTRACT

Unusually steep maturation profiles from over thirty drill holes spread throughout the Pacific Northwest imply near-constant maturity with respect to oil and gas over thousands of feet of sediment. Given the consistency of the data, the widespread occurrence of this type of maturation anomaly must be inferred to be a real and systematic phenomenon. In addition, the diverse sources of data and the qualitative agreement among the major maturation indicators support the model of a real maturation process that may be unique to such a geologically active area. Examination of the stratigraphy and maturation profiles of individual drill holes in the Pacific Northwest leads to the conclusion that the dominant maturation process is related to hydrothermal fluids associated with volcanic activity. This hypothesis implies that the source of the gas in the Mist Gas Field, Columbia County, Oregon, may be located in intruded sediments to the northeast and northwest of the field. In addition, vitrinite reflectance data from the Pacific Northwest cannot be interpreted using conventional models such as the Lopatin method, as short-term thermal events have overprinted the maturation data. Therefore an approach based on the concept of an "oil window" may be more appropriate, given the complex geological histories of basins within a tectonically active area such as the Pacific Northwest.

INTRODUCTION

Consideration of all of the available data from the Pacific Northwest reveals a pattern of anomalous maturation profiles that defy conventional interpretation. These unusual profiles are very steep, implying near-constant maturity with respect to oil and gas generation over thousands of feet of sediment. In this paper we examine the data and address the question of whether the anomalous profiles represent a real phenomenon.

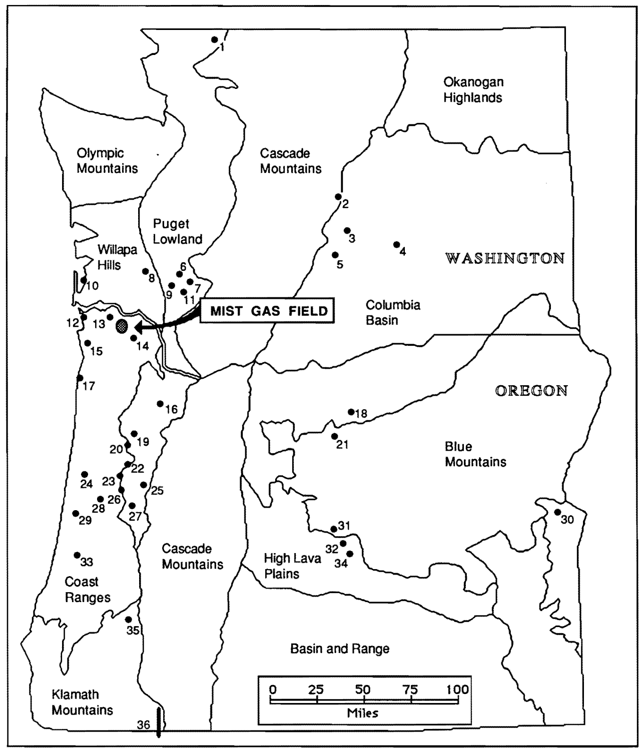

Figure 1. Physiography and location of drill holes in the Pacific Northwest with available maturation data. Numbered drill holes are keyed to well names and locations in Table 1.

MATURATION METHODS

Various organic geochemical methods are commonly used to ascertain the maturity and source rock potential of a sediment. These methods are used mainly to define the zone of peak hydrocarbon generation in source rocks so that updip reservoir rocks can be targeted for drilling. One such method, vitrinite reflectance (R_O), comprises the bulk of the maturation data on sediments in the Pacific Northwest. Vitrinite reflectance is based on the changes in the optical properties of vitrinite, which occur primarily in response to heating. During heating, the chemical composition of the organic matter in a sediment is irreversibly altered by a cracking process that generates volatile products such as CH_4 and H_2O. Cracking causes the organic matter molecules to restructure with a higher degree of order, increasing their reflectance. Vitrinite is one component of organic matter, and its reflectance increases in a uniform manner. Initially used to evaluate coal rank, vitrinite reflectance is now the most widely used optical technique in the petroleum industry for determining the maturity of a source rock.

The vitrinite reflectance technique has been developed over many years. International standards now define most of the steps in the acquisition of data (Baskin, 1979), although different approaches are used for the extraction of the organic matter and the subsequent preparation of polished sections. When vitrinite reflectance values are plotted on a logarithmic scale versus depth on a linear scale, the result is usually a straight line of increasing reflectance with depth (Dow and O'Connor, 1982). Deviation from a uniform slope can provide important geological information. For example, the location of an unconformity and the amount of section removed at the unconformity is commonly obtained by extrapolating the vitrinite reflectance profile back to R_O = 0.2 percent at the paleosurface (Dow and O'Connor, 1982). There are two methods for interpreting the thermal history of sediments using vitrinite reflectance data: (1) conventional approaches based on time/temperature relationships, one being the Lopatin technique (Waples, 1980); and (2) an approach that treats vitrinite reflectance as an absolute geothermometer (Price, 1983; Barker and Pawlewicz, 1986).

Over the past decade, extensive studies by the petroleum industry have resulted in a cross-calibration of vitrinite reflectance with two other maturation indicators. The Thermal Alteration Index (TAI), a well-established method, is based on the color changes that organic particles experience with increasing maturation or temperatures (Staplin, 1982). Rock-Eval pyrolysis is based on the release of volatiles during heating of whole-rock samples and provides information on thermal maturation (T_{max}) as well as the quantity and type of organic matter in the sediment. Rock-Eval pyrolysis has become accepted by the petroleum industry as a rapid, quantitative method for source rock evaluation.

TECHNIQUE LIMITATIONS

Although vitrinite reflectance is a widely used and accepted indicator of thermal maturation, there are problems associated with the technique. First, the method is subjective because the microscope operator must identify and measure only unweathered, unoxidized vitrinite, and the ability to do this is a function of the operator's

Table 1. *Published and public-domain maturation data from the Pacific Northwest.*

Ref#	Drill hole	Position	Ro at	depth (Ft)	Reference	Comment
1	Daymont, Stremler #2	T40N, R 3E, Sec.4	0.55-0.52	1,390-4,720'	4	
2	Norco, Norco #1	T22N, R 20E, Sec.26	0.39-0.51	1,751-4,850'	8	Under Columbia River Basalt Group (CRBG)
3	Shell, Bissa 1-29	T18N, R 21E, Sec.29	0.43-0.57	4,620-10,080'	8	Under CRBG
4	Shell, BN 1-9	T15N, R 25E, Sec.9	0.54-1.32	11,280-15,820'	8	Under CRBG
5	Shell, Yakima Minerals 1-33	T15N, R 19E, Sec.33	0.86-1.38	9,840-11,870'	8	Under CRBG
6	Humble, Everett Trustee	T13N, R 1E, Sec.23	0.63-0.53	1,800-3,101'	4	Hydrothermal effects
7	Humble, Rosa Meyer	T12N, R 2E, Sec.8	0.40-0.60	1,607-4,080'	4	Normal
8	Shell, Thompson #1	T12N, R 1W, Sec.34	0.27-0.44	278-7,468'	3	Retarded/ coal seam/ mud additive ?
9	Humble, Roscoe B. Perry	T12N, R 1W, Sec.12	0.31-0.52	1,320-9,540'	4	Marked effects of intrusion
10	Tidelands, Weyerhauser 7-11	T11N, R10W, Sec.7	0.38-0.92	400-5,990'	3	Under 5,000' of basalts, overthrust?
11	Humble, John Brown #1	T11N, R 1E, Sec.15	0.47-0.48	40-3,454'	4	Retarded/ coal seam/ mud additive ?
12	Standard, Hoagland	T 7N, R10W, Sec.11	0.3-0.43	520-7,090'	3, 6	Retarded?, interlayered basalts
13	Diamond, Boise Cascade 1-14	T 7N, R 7W, Sec.14	0.41-0.46	840-7,440'	3, 7	Constant, near Mist Gas Field
14	Texaco, Clark & Wilson 6-1	T 6N, R 4W, Sec.19	0.25-0.64	485-8,405'	3, 6	Volcanic effects
15	Crown Zellerbach 31-17	T 5N, R 9W, Sec.28	0.4-2.4	1,000-5,000'	7	+600 m effect of gabbroic sill
16	Texaco, Cooper Mountain	T 1S, R 2W, Sec.25	0.63-0.44	2,808-8,100'	3, 6	Under CRBG
17	Reichold, Crown Zellerbach	T 2S, R10W, Sec.22	0.36-0.41	680-5,120'	3	Retarded?
18	Standard, Kirkpatrick #1	T 4S, R21E, Sec.6	1.01-1.15	6,846-8,720'	1, 3, 9	Under Clarno, John Day, and CRBG
19	Reichold, Finn #1	T 6S, R 4W, Sec.17	[421-433]	490-6,310'	3, 6	Near-constant, T_{max} only
20	Reserve, Bruer #1	T 6S, R 4W, Sec.31	0.46-0.52	1,660-4,380'	10	Near-constant
21	Oregon, Clarno #1	T 7S, R19E, Sec.27	[433-437]	1,000-3,200'	3, 9	Melange, under Clarno, T_{max} only
22	Quintana, Gath #1	T 8S, R 2, Sec.16	0.50-0.67	4,020-5,925'	10	Intercalated volcanics 1200-5700'
23	Humble, Miller #1	T10S, R 3W, Sec.10	0.52-0.56	1,415-4,430'	10	
24	Oregon O&G, Robert #1	T10S, R 8W, Sec.25	3.5-2.5	340-2,415'	10	
25	Reserve, Esmond #1	T12S, R 1W, Sec.7	0.51-0.54	2,920-3,805'	6, 11	Steep
26	American Quasar, Hickey	T12S, R 2W, Sec.9	0.49-0.46	1,800-4,670'	10	
27	Gulf, Porter #1	T13S, R 4W, Sec.27	0.38-0.55	600-7,940'	3, 6	Effects of 2,500' volcanics
28	Mobil, IRA Baker	T15S, R 3W, Sec.28	0.49-1.26	1,130-10,125'	10	Intercalated basalts 2800-6700'
29	Sinclair, Federal-Mapelton	T16S, R10W, Sec.12	0.64-0.64	270-6,520'	3, 6	Vertical, good agreement with T_{max}, TAI
30	Sinclair, Eastern Oregon Land	T16S, R44E, Sec.15	1.57	at 4,430'	3	Within volcanics
31	Sunray, Bear Creek #1	T17S, R19E, Sec.30	0.78-1.18	3,180-7,165'	1, 3, 5,11	Steep, geothermal effects
32	Texaco, Logan Butte #1	T19S, R20E, Sec.17	1.11-1.26	2,005-6,475'	11	Near-constant, hydrothermal effects
33	General, Long Bell	T20S, R10W, Sec.27	0.46-0.58	530-6,880'	3, 6	Near-constant, hydrothermal effects
34	Standard, Pexco State #1	T20S, R20E, Sec.36	0.58-1.3	5,920-7,386'	3	Under thick volcanics
35	Mobil, Sutherlin	T24S, R 5W, Sec.36	0.48-0.57	460-3,850'	3	Vertical, good agreement with T_{max}, TAI
36	Hornbrook Fm.	CA/OR Borderlands	0.6-0.52	over ≈3,300'	2	Under thick volcanic strata

[ ] = T_{max}

Key to numbered references: 1 = Newton, 1979. 2 = Law and others, 1984b. 3 = Brown and Ruth Laboratories, Inc., 1983 (Contract 1)*. 4 = Amoco Production Co., 1981-1983**. 5 = Green and Associates, 1982 (Contract 3)*. 6 = Ogle Petroleum, 1981 (Contract 2)*. 7 = Niem and Niem, 1985. 8 = Lingley and Walsh, 1986. 9 = L.H. Fisk, personal communication, 1986. 10 = Sohio Petroleum Co., 1984 (Contract 10)*. 11 = Summer and Verosub, 1987.

*Data released by Oregon Department of Geology and Mineral Industries.

**Data released by Washington Division of Geology and Earth Resources.

training and experience. Second, different extraction and polishing procedures can lead to widely differing values being reported for the same sample (Dembicki, 1984). Another problem with vitrinite reflectance is that its normal increase due to rising temperatures may be subject to an effect known as retardation (Price and Barker, 1985).

TAI is also a widely accepted method, although it is highly subjective because a microscope operator must match the color of the organic particles to colors on standardized charts. On the other hand, Rock-Eval pyrolysis is an automated, objective technique, but it is not without problems (Katz, 1983; Peters, 1986). Importantly, Rock-Eval data are most easily reproduced in interlaboratory comparisons (Dembicki, 1984).

In fact, the reproducibility of most organic geochemical data between laboratories is not good, with the result that interlaboratory comparison of maturation data is often not possible. A further problem common to all the techniques is that most maturation data are based on rock cuttings taken at the well head at the time of drilling, and caving and mud contamination can be major causes of error.

MATURATION DATA FROM THE PACIFIC NORTHWEST

Published maturation studies from Oregon are primarily based on weathered outcrop samples (Law and others, 1984a,b; Armentrout and Suek, 1985; Sidle and Richers, 1985), although three subsurface source rock evaluations are available (Newton, 1979; Niem and Niem, 1985; Summer and Verosub, 1987). Similar work in Washington is based mainly on subsurface samples (Walsh and Phillips, 1982; Lingley and Walsh, 1986). However, extensive unpublished data are available from the state core repositories of Oregon and Washington, primarily on drill cuttings.

Analysis of all the available maturation data (including R_O, TAI, and T_{max}) (Figure 1, Table 1) reveals that the maturation profiles from drill holes in the Pacific Northwest are remarkable for the persistent occurrence of unusually steep maturation profiles (Figures 2-4). Moreover, in some instances, vitrinite reflectance values fail to increase from nascent levels (R_O = 0.4 percent) even though buried to depths of 6,000-8,000 ft in areas of normal geothermal gradient (Table 1, drill holes 2, 8, 12, 14). When corresponding R_O, TAI, and T_{max} data are available for the same drill hole, they generally show agreement in maturation profile, even if the maturation levels are not comparable. Therefore, some underlying geologic process must be responsible for the anomalous maturation gradients in the drill holes of the Pacific Northwest.

DISCUSSION.

We will not attempt to examine in detail the available data, given the fact that maturation data from different laboratories cannot be directly compared. For example, consistent with Dembicki (1984), the four independent studies on a drill hole in north-central Oregon (Figures 2A,B) indicate significantly different maturation levels. More importantly, however, the profiles or best-fit lines for each data set are all anomalously steep, showing that all of the studies are consistent in implying an unusual maturation process. Further examination of the data base reveals that the unusual maturation profiles that prevail within most of the drill holes in the Pacific Northwest are independent of the laboratories that generated the data. Therefore, given the widespread occurrence of drill holes with steep maturation profiles, the diverse sources of the data, and the agreement between the different maturation techniques, the profiles are interpreted to be real and not the result of some methodological error.

As previously mentioned, in some individual drill holes, vitrinite reflectance levels are remarkably low, compared to TAI and T_{max} results. One possibility is that the results are due to retardation of vitrinite reflectance. This has been reported to occur in sediments with appreciable amounts of exinite or hydrogen-rich Type II kerogens (Price and Barker, 1985). However, the sediments of the Pacific Northwest generally have low hydrogen contents probably due to an aerobic depositional environment (Armentrout and Suek, 1985), and Type II kerogen does not predominate. While retardation may account for some anomalously low vitrinite reflectance data in central Washington (drill hole 2), near the Mist Gas Field in northwest Oregon (drill holes 12, 13, 14), and elsewhere (drill holes 6, 8) where Type II hydrogen-rich strata occur, it cannot be shown to have occurred systematically over the data base.

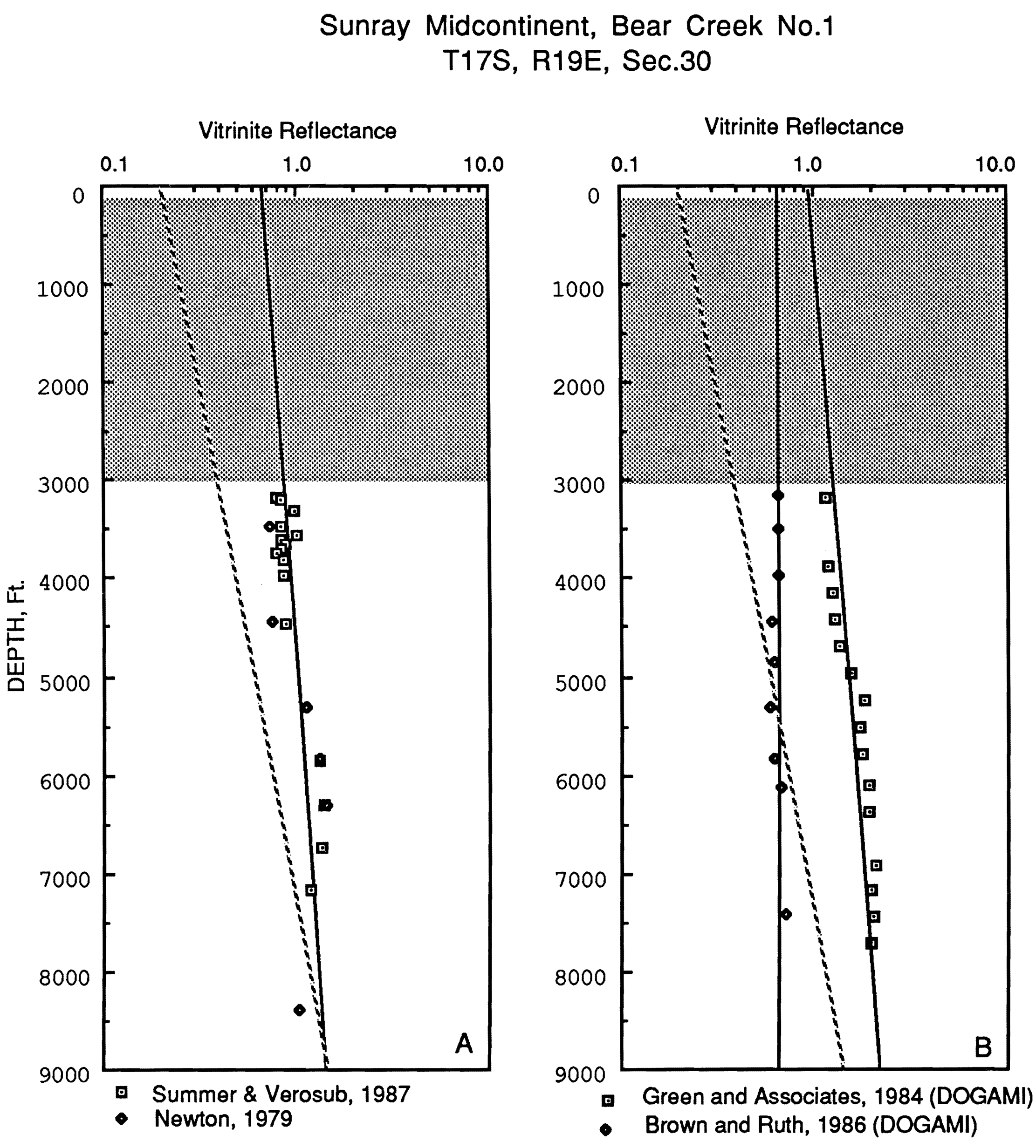

Figure 2. Data from four different studies of drill hole 25. Solid lines are best-fit profiles through the individual data sets. The two studies in Figure 2A give consistent results and can be treated as a single data set. Dashed lines are the "normal" profile. Extrapolation of the solid lines implies unrealistically that about 10,000 ft of erosion has occurred. Overlying volcanic rocks (shaded) are of the Clarno Formation. Data in Figure 2B were released by the Oregon Department of Geology and Mineral Industries (DOGAMI), Portland (see references in Table 1).

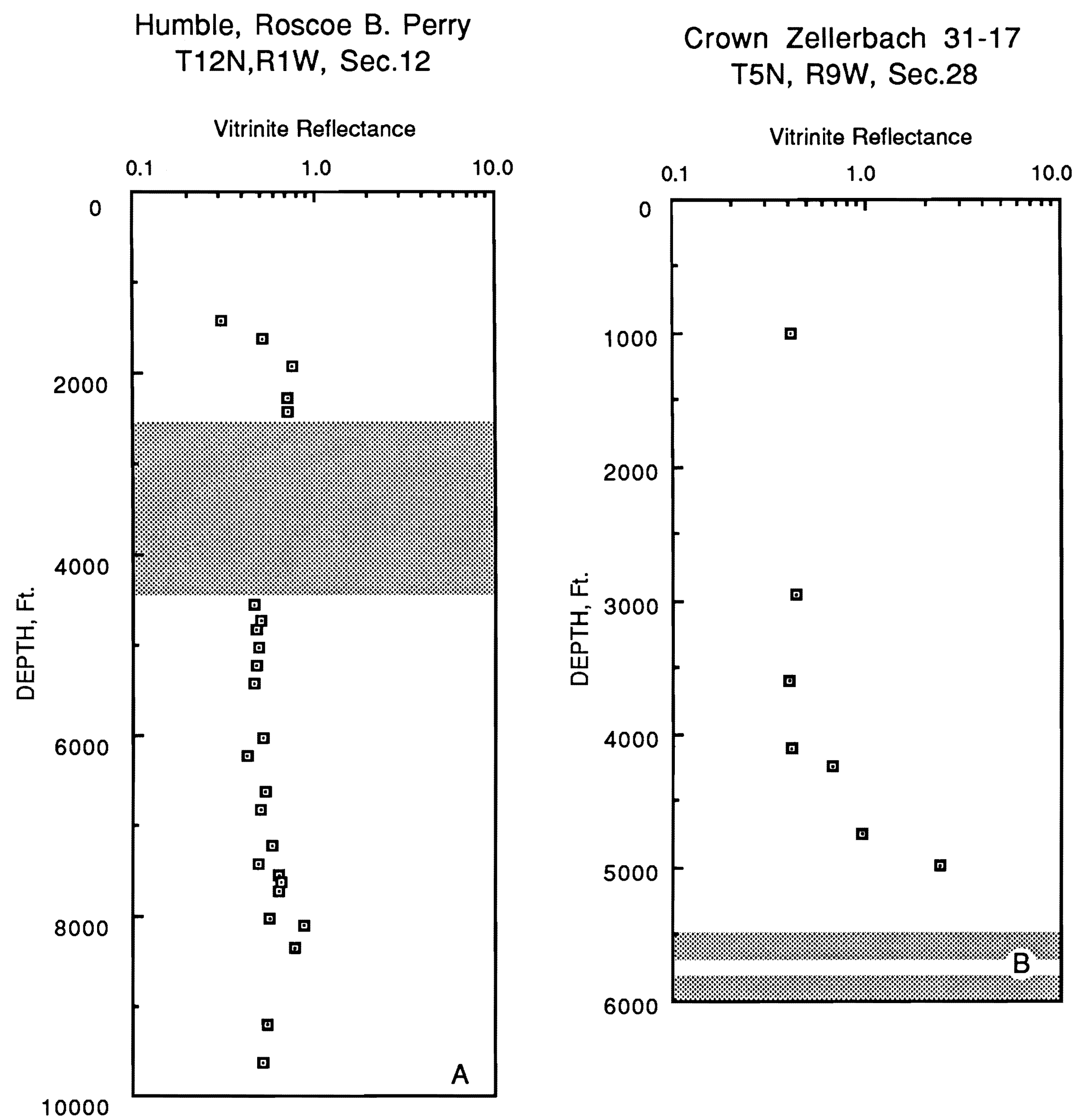

Figure 3. Data from southwest Washington (A = drill hole 9) and northwest Oregon (B = drill hole 15). Drill holes are less than 40 mi from the Mist Gas Field, Oregon. Data in A are from a study by Amoco Production Co. and released by the Washington Division of Geology and Earth Resources, Olympia (see reference in Table 1). Data in B are from Niem and Niem, 1985. The intrusive bodies (shaded) have not been named or dated at the present time.

Anomalous maturation profiles in the Pacific Northwest drill holes generally occur where sediments are mantled or intruded by volcanic rocks, although in some instances no volcanic rocks are present (drill holes 1, 27). Intrusive and extrusive volcanic rocks are known to have a direct thermal effect on country rock, but these effects are overshadowed by associated hydrothermal effects. We have suggested that the unusual near-constant maturation profiles are the result of the thermal effects of hydrothermal aquifers perched high in the rock column (Summer and Verosub, 1987). Such aquifers can be found in any highly permeable strata, and fractured volcanic rocks as well as porous sediments can provide the necessary conduits. These aquifers can be wide-ranging in extent, and their thermal effects on underlying sediments have been simulated by Ziagos and Blackwell (1981) and documented by Wood and Low (1986).

Thermal fluids from generations of Cascade volcanism may have affected a wide area (Walsh and Phillips, 1982), and there is evidence that emplacement of the Columbia River Basalt Group was preceded by a thermal event with coincident hydrothermal activity east of the Cascades (Summer and Verosub, 1987). Thus, marked maturation perturbations (drill holes 6, 9, 15, 22, 26) and extensive evidence of fossil hydrothermal systems suggest that fluids associated with intrusive and extrusive bodies have assisted in the maturation of sedimentary units throughout the Pacific Northwest. This mechanism thus implies a much wider diagenetic influence of intrusive activity, well beyond contact metamorphic effects (Summer, 1987).

The anomalous maturation profiles cannot be explained using conventional techniques used to integrate the effects of temperature and time on organic maturation. For example, the widely used Lopatin method is based on a calculated time-temperature interval (TTI) derived solely from vitrinite reflectance data (Waples, 1980). Because of the assumptions of the method, the Lopatin technique cannot account for strata of different geological age with the same TTI. To do so would require that the sedimentary units had been subject to downwardly decreasing temperatures. In addition, the maximum burial depth usually obtained from extrapolation of the vitrinite reflectance profile gives unrealistic values (Figures 2A,B). These

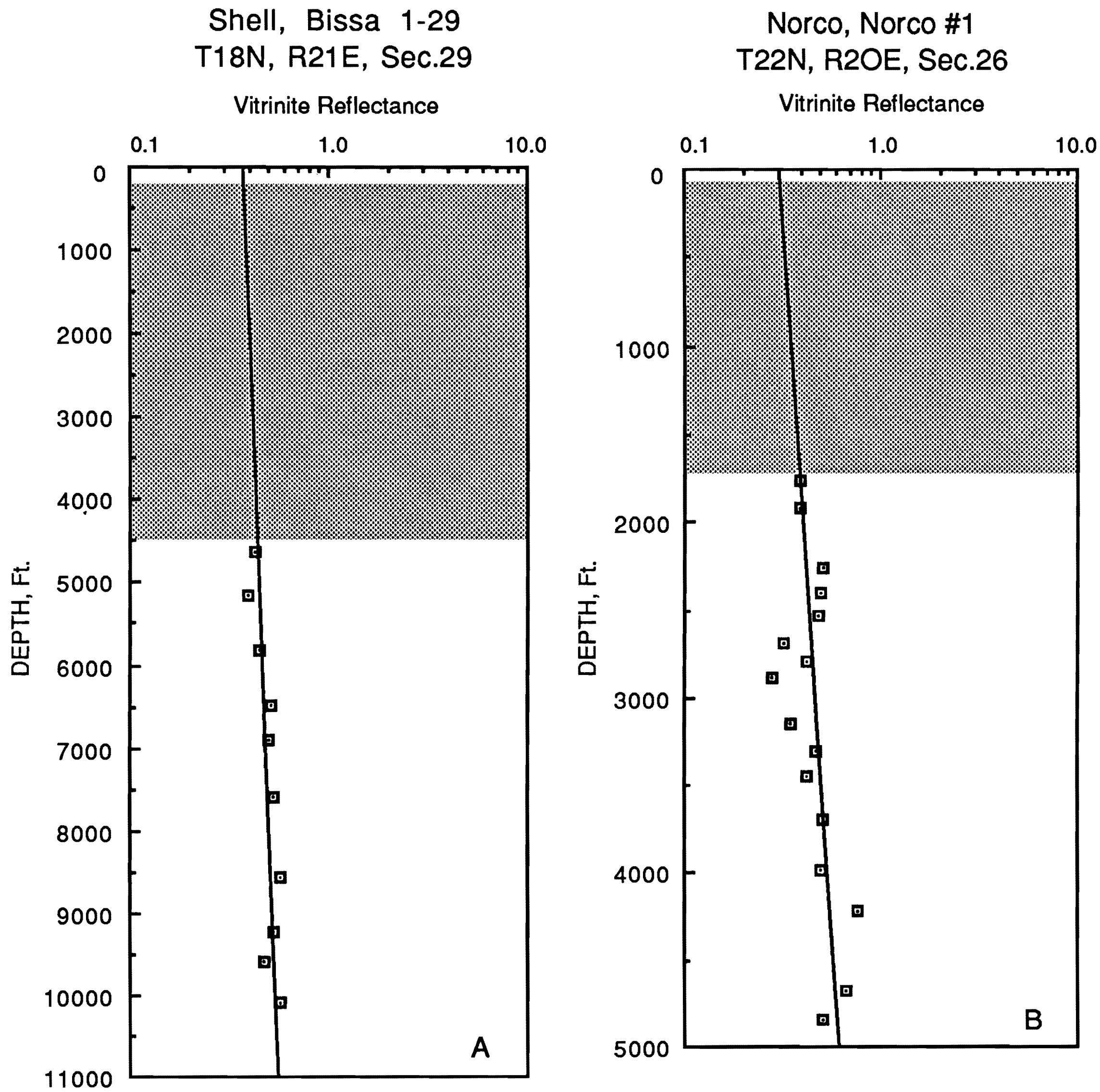

Figure 4. Data from drill holes 3 (A) and 2 (B), central Washington, after Lingley and Walsh (1986), presented with permission of T.J. Walsh. Overlying volcanic rocks (shaded) are of the Columbia River Basalt Group.

limitations, in addition to assumptions regarding the thermal fluxes over geological time (usually based on a combination of the local tectonics and again on the R_O values), make the use of the Lopatin method in these circumstances questionable.

Particularly ignored in the Lopatin model is the importance of transient thermal events (<200,000 years) in maturing sediments, although the effects of hydrothermal systems and intrusives are known to have produced hydrocarbons (Altebaumer and others, 1983; Reiter and Clarkson, 1983; and many others). Since important exploration decisions are based on these Lopatin plots, a more objective method based on an oil window of approximately R_O = 0.6-1.4 percent pertaining to Type III kerogen should be utilized. Although the Lopatin technique may work well in tectonically quiescent terranes, its use is not appropriate in volcanically or tectonically active areas.

Low maturation levels in sediments around the Mist Gas Field have led to uncertainty with regard to the source of the gas in the field. Yet there are sediments on both sides of the field and within the structure upon which the field is found that have experienced heating from igneous intrusives (Figure 3)(Niem and Niem, 1985; Summer, 1987). The maturation data from these downdip sediments indicate that they are within the oil generative window (drill holes 9 [see Figure 3A], 14, 15). In addition, the coals of the Skookumchuk Formation in the Centralia area of Washington (Figure 1), 30 mi northeast of the field, show elevated coal rank (R_O = 0.3-0.42)(Hadley, 1981), yet were never buried to more than 1,500 ft (Walsh and Phillips, 1983). The Skookumchuk Formation correlates stratigraphically with the reservoir sands of the Mist Gas Field, and this area lies on the eastern flank of the structure upon which the field is found (Armentrout and Suek, 1985). Armentrout and Suek (1985) concluded that the source of the gas lay to the east, under the cover of the Columbia River Basalt Group. We support these conclusions, as the fluids expelled by the emplacement of the aforementioned intrusive bodies may not only have matured the sediments and coals of the area but may also have assisted in the transport of the gas to the field 40 mi away.

CONCLUSION

The near-vertical maturation profiles in the Pacific Northwest are a real and systematic phenomenon implying near-constant maturity with respect to oil and gas over thousands of feet of sediment. Agreement among the major maturation indicators over a broad data base suggests a real maturation process that may be unique to such a geologically active area, namely thermal input from warm-water aquifers within the sedimentary column. Given the widespread effects of such aquifers and their effects on underlying sediments, the systematic occurrence of near-constant maturation profiles throughout the area should be expected.

Understanding the unusual maturation processes is made more difficult by problems with the major maturation indicators and the fact that data from different sources are not amenable to direct comparison. However, examination of the stratigraphy and maturation profile of individual drill holes leads to the conclusion that the maturation process is related to hydrothermal fluids associated with volcanic activity. Furthermore, hitherto unpublished data indicate that the source of the gas in the Mist Gas Field may lie in intruded sediments to the northeast and northwest.

Interpretation of the vitrinite reflectance data from the Pacific Northwest cannot be done in the conventional manner because such methods cannot accommodate short-term thermal events. As an alternative method of interpreting the unusual maturation data from the Pacific Northwest, an approach based on the established "oil window" is more appropriate, given the complex geological histories of basins within such a tectonically active area.

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Ziagos, J.P., and Blackwell, D.D., 1981, A model for the effect of horizontal fluid flow in a thin aquifer on temperature-depth profiles: Geothermal Resources Council Transactions, v. 5, p. 221-223. □

New map describes geology of Breitenbush River area

The complex volcanic geology of the Breitenbush River area is described and discussed in a new publication of the Oregon Department of Geology and Mineral Industries (DOGAMI). The area is located at the transition between the older Western Cascade Range and the younger High Cascade Range and has been known for its thermal springs and, in some parts, for its mineral potential.

Geologic Map of the Breitenbush River area, Linn and Marion Counties, Oregon, by DOGAMI staff geologists G.R. Priest, N.M. Woller, and M.L. Ferns, has been released in DOGAMI's Geological Map Series as map GMS-46. It covers over 200 square miles, extending from Detroit Lake 12 miles to the east and from Hawk Mountain in the north to Bachelor Mountain in the south.

The report consists of two parts, a map sheet and a 4-page text. The map sheet (approximately 27 by 40 inches) contains a multicolored geologic map (scale 1:62,500), a geologic cross section, a location map, and a table listing ages of almost 50 samples from the area. The map explanation identifies and describes 50 separate units of surficial and volcanic rocks, vent complexes, and intrusives. The accompanying text discusses the structural geology, mineralization, and geothermal resources of the study area and presents a table of radiometric data for some rock-unit samples collected outside the map area.

The new map GMS-46 is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $6. Orders under $50 require prepayment. □

Oregon surface-water resources detailed in National Water Summary

Oregon's surface-water resources provide about 85 percent of the state's total water needs. Use is limited in part by the uneven distribution of surface water across the state, according to the Oregon section of the 1985 National Water Summary by the U.S. Geologic Survey (USGS), Department of the Interior.

The 1985 National Water Summary is the third in an annual series of comprehensive reports on the status and supply of the nation's vital water resources. It provides an extensive state-by-state look at the country's surface-water resources, which provide about 80 percent of the daily water needs of the United States.

"Western Oregon has a good supply of surface water, whereas surface water is a limited resource in eastern Oregon," said Marvin O. Fretwell, chief of the USGS Water Resources Division office in Portland, Oregon. "Many of the smaller streams in eastern Oregon are dry by summer's end, but the larger streams, which follow a similar seasonal pattern, still flow in late summer. Reservoir storage is necessary throughout the state to augment summer flows with captured winter and spring runoff.

"The efficient use of surface-water supplies is an important state water issue, and one that is severely limited because of the competitive and sometimes incompatible demands for surface water. The many competitive demands involve municipal supplies, irrigation, Indian lands, industry, recreation, fisheries and hydroelectric power. Specific issues of current concern are the establishment of minimum flows for instream use and the sustained flooding of Malheur and Harney Lakes," Fretwell said.

The Oregon Water Resources Department (OWRD) has the major responsibility for managing the state's surface and ground waters for beneficial uses. The OWRD also has the responsibility of ensuring that water supplies are adequate for human consumption.

The OWRD is the principal cooperator with the USGS in investigating the state's surface-water resources. These activities include data collection, data analysis, and interpretive studies that together form an information base for surface-water planning and management.

The Oregon Department of Environmental Quality is responsible for establishing and enforcing rules designed to prevent contamination of Oregon's surface-water resources. Each state section contains maps and graphs that portray runoff and precipitation; the location of principal rivers, reservoirs and hydropower plants; trends in average streamflow discharge; how surface-water resources are managed and a table on surface-water use.

Copies of the 506-page 1985 National Water Summary including all state sections plus an overview of hydrologic conditions for the 1985 water year and articles on record-high levels of the Great Lakes, the disintegration of Columbia Glacier, snow and ice and their effects on climate and transferring water to meet water needs, among others, are available for $31.00 each. Orders must include check or money order payable to Department of the Interior-USGS and should be directed to: U.S. Geological Survey, Books and Open-File Reports, Federal Center, Bldg. 41, Box 25425, Denver, CO 80225.

Single copies of the Oregon section of the 1985 National Water Summary are available from the Oregon Office, U.S. Geological Survey, Suite 300, 847 N.E. 19th Ave., Portland, OR 97232.

Selected Oregon surface-water facts from the 1985 National Water Summary compiled by the USGS in cooperation with state and local agencies:

- Irrigation comprises 88 percent of the total water used in Oregon; surface water provides 85 percent of the water used for irrigation. Many of the major cities, such as Portland, Salem, Eugene, Corvallis, Pendleton, Coos Bay, and Astoria, depend on surface water as their primary source of supply.
- Oregon is second only to Washington in the amount of water used for hydroelectric power. In fact, Oregon and Washington used more water for hydroelectric power than all of the eastern States combined.

— USGS news release

USGS tests implementation of mapping changes

The National Geodetic Survey has completed the readjustment of the horizontal control net, creating the new North American Datum 1983 (NAD 83) to replace the present North American Datum 1927 (NAD 27). The present NAD 27 is based on the Clarke 1866 ellipsoid, while NAD 83 is an Earth-centered datum based on the newly adopted Geodetic Reference System 1980 ellipsoid.

In consequence of the adoption of the new ellipsoid base, two mapping grids will have their locations changed in respect to the geographic coordinates and with each other: the State Plane Coordinate Systems and the Universal Transverse Mercator grid.

Conversion to NAD 83 will be of increased importance as use is made of satellite-derived data that basically are referenced to the center of mass of the Earth. The conversion will also remove known existing anomalies in the horizontal network.

The U.S. Geological Survey (USGS) is faced with the problem of converting nearly 55,000 maps to the new NAD 83. The evaluation of many options, ranging from continuing on NAD 27 to recompiling the maps on NAD 83, has now led to a pilot project in which a conversion is tested. The project consists of 36 7½-minute maps covering the State of Rhode Island and uses a cartographic adjustment that holds the existing map detail limits.

Oregon State Resident Cartographer Glenn Ireland has provided the following table showing how much the geographic values of features change in Oregon due to the new NAD 83. The table compares the NAD 27 and NAD 83 geographic values for points at opposite corners of the State.

NW Oregon (Station ASTOR)

	NAD 27	NAD 83	Difference
Latitude	46°10′53.413″	46°10′52.801″	0.612″S (19 m)
Longitude	123°48′58.707″	123°49′03.202″	4.495″W (96 m)

SW Oregon (Station ONIDA)

	NAD 27	NAD 83	Difference
Latitude	42°01′37.904″	42°01′37.510″	0.394″S (12 m)
Longitude	117°02′20.215″	117°02′23.677″	3.462″W (80 m)

Differences in the mapping grid systems would not be the same as in the geographic values because of concomitant changes in the system parameters.

The USGS invites written comments from interested persons to: Chief, National Mapping Division, U.S. Geological Survey, 510 National Center, Reston, VA 22092.

An inspection packet is available that contains a quadrangle map from the Rhode Island pilot project and additional explanations, the map sheet showing the quadrangle based on NAD 27 on one side and based on NAD 83 on the other side. The packet may be obtained from the Portland office of the USGS National Mapping Division, 847 NE 19th, Suite 300, Portland, OR 97232, phone (503) 231-2019. □

Glimpses of DOGAMI history—On the moon in Oregon

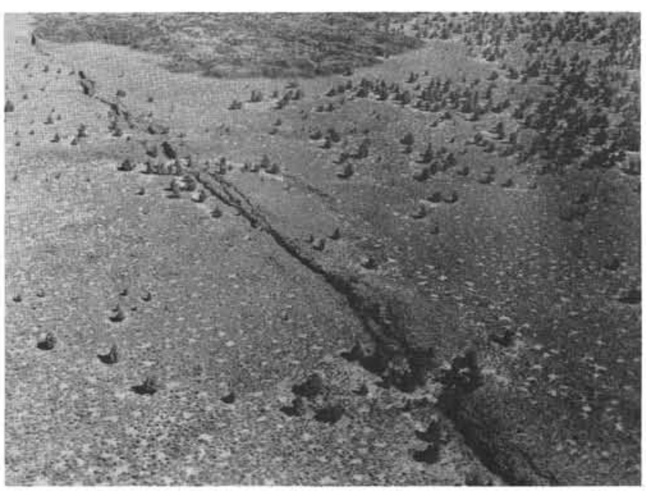
Between 1960 and 1965, the Oregon Department of Geology and Mineral Industries (DOGAMI) saw considerable involvement in the exploration and research that eventually put U.S. astronauts on the moon.

Rock samples and photographs were provided for the National Aeronautics and Space Administration (NASA) and a large number of companies working on technology and instrumentation for the lunar landing—even as late as 1967, when lunar reference rocks from Oregon were shown at the EXPO '67 in Montreal, Canada. Counseling, guidance, and assistance were given to a variety of visitors related to the lunar program: Scientists came from the U.S. Geological Survey and its astrogeology branch, from aircraft companies such as Boeing, and from NASA-related research institutions. Several groups of NASA astronauts were trained in Oregon in techniques they used to move about and explore the moon's surface. Even a CBS television team arrived to film astronauts in Oregon's "lunar environment."

In 1965, this activity culminated for DOGAMI in the cosponsorship (with the New York Academy of Science) of the International Lunar Geological Field Conference. The same year also saw the establishment of the Center for Volcanology at the University of Oregon.

Why in Oregon? — Well, certain areas of central and southeastern Oregon show volcanic landforms quite similar to the volcanic features one expected to find on the lunar surface. The barrenness or sparse vegetation of such recent and thus relatively fresh, unweathered volcanic terranes as the areas at Diamond Craters, Newberry volcano, Hole-in-the-Ground, Devils Garden, Crack-in-the-Ground, and Jordan Craters invited the comparison with the moon—as the pictures on this page demonstrate. □

Twin Craters, Diamond Craters area, Harney County



Crack-in-the-Ground, Devils Garden area, Lake County

Cinder cones, Devils Garden area, Lake County

Hole-in-the-Ground, Lake County

Lava field, Jordan Craters area, Malheur County

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-4: Oregon gravity maps, onshore and offshore. 1967	$ 3.00		
GMS-5: Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00		
GMS-6: Preliminary report on geology of part of Snake River canyon. 1974	6.50		
GMS-8: Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-9: Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
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GMS-17: Total-field aeromagnetic anomaly map, south Cascades, Oregon. 1981	3.00		
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GMS-19: Geology and gold deposits map, Bourne 7½-minute quadrangle, Baker County. 1982	5.00		
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GMS-21: Geology and geothermal resources map, Vale East 7½-minute quadrangle, Malheur County. 1982	5.00		
GMS-22: Geology and mineral resources map, Mount Ireland 7½-minute quadrangle, Baker/Grant Counties. 1982	5.00		
GMS-23: Geologic map, Sheridan 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-24: Geologic map, Grand Ronde 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-25: Geology and gold deposits map, Granite 7½-minute quadrangle, Grant County. 1982	5.00		
GMS-26: Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00		
GMS-27: Geologic and neotectonic evaluation of north-central Oregon: The Dalles 1°x2° quadrangle. 1982	6.00		
GMS-28: Geology and gold deposits map, Greenhorn 7½-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-29: Geology and gold deposits map, NE¼ Bates 15-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-30: Geologic map, SE¼ Pearsoll Peak 15-minute quadrangle, Curry/Josephine Counties. 1984	6.00		
GMS-31: Geology and gold deposits map, NW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-32: Geologic map, Wilhoit 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-33: Geologic map, Scotts Mills 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-34: Geologic map, Stayton NE 7½-minute quadrangle, Marion County. 1984	4.00		
GMS-35: Geology and gold deposits map, SW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-36: Mineral resources map of Oregon. 1984	8.00		
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GMS-38: Geologic map, NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	6.00		
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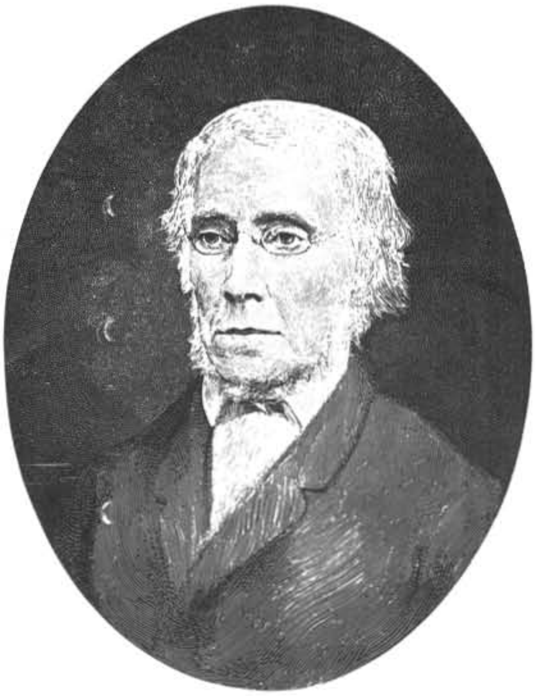
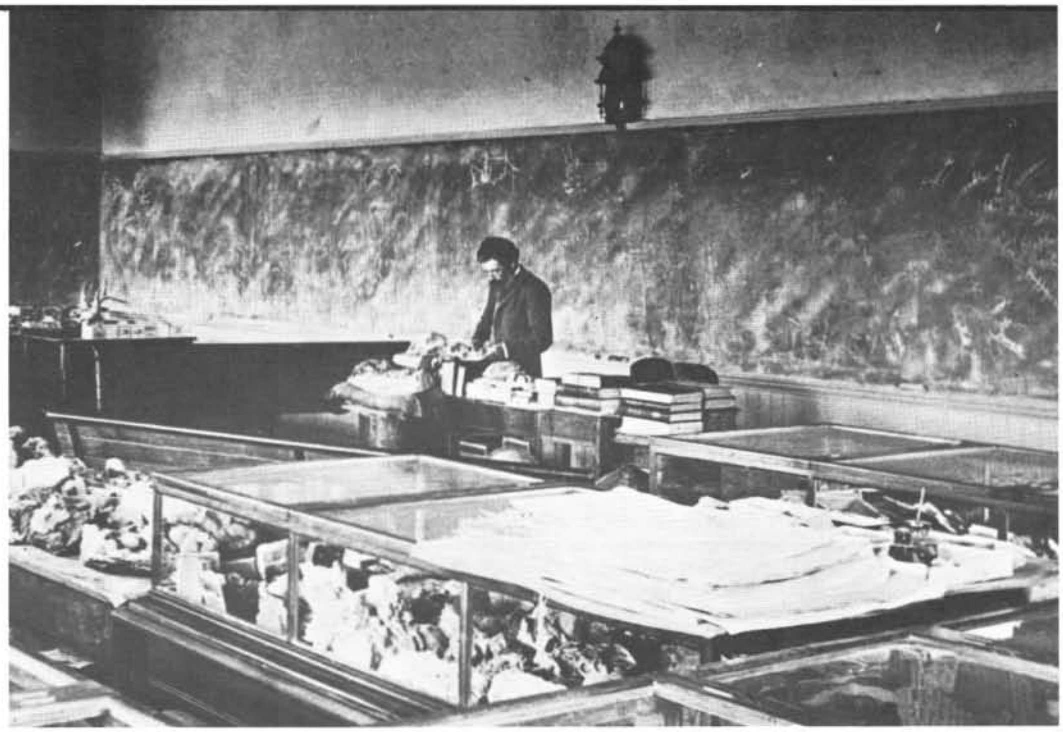
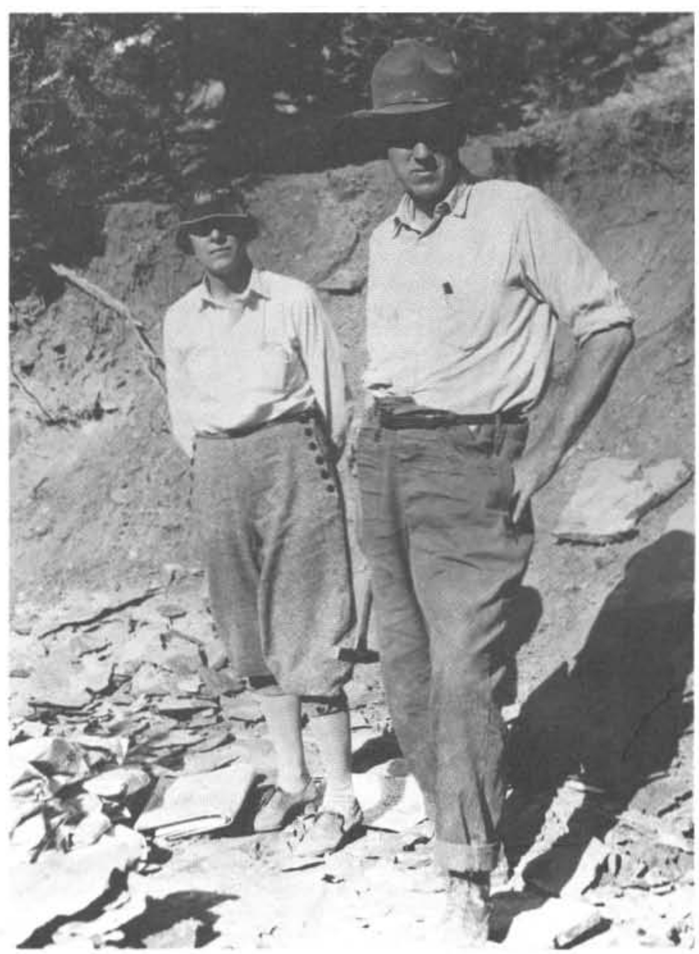




Paleontology in Oregon: Workers of the past



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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Some of the early paleontologists who worked in Oregon and are discussed in article beginning on next page (clockwise, beginning at top left): Timothy Conrad (photo courtesy Ellen J. Moore, USGS). Thomas Condon in his classroom-laboratory at the University of Oregon (photo courtesy University of Oregon Archives). Ralph Chaney collecting fossil leaves, probably at the West Branch of Bridge Creek locality near Mitchell; the woman is not identified (photo courtesy University of Oregon Archives, Phil Brogan Collection). Jacob L. Wortman standing before some of his fossil dinosaur finds at the American Museum of Natural History (photo courtesy Dorothy Gunness, McMinnville, Oregon).

OIL AND GAS NEWS

Mist Gas Field

ARCO has drilled the well Columbia County 34-4-65 to a total depth of 3,382 ft and has run production casing. The well is currently suspended, awaiting completion. ARCO drilled the Columbia County 42-9-65 to a depth of 2,850 ft and, after abandoning the well, redrilled to a depth of 2,840 ft and plugged and abandoned the well. This is the first dry hole of the year for ARCO after five successful wells. ARCO next plans to drill the Columbia County 21-35-65, which has a proposed total depth of 1,900 ft.

Completion tests were done by ARCO on the Columbia County 31-27-65 and Columbia County 31-34-65 wells, and they are currently suspended, awaiting connection to gas pipeline. Production rates have not yet been released. □

New report provides detailed geology of Broken Top area

A new report published by the Oregon Department of Geology and Mineral Industries (DOGAMI) provides detailed geologic descriptions of an area near the Three Sisters and Broken Top in the Cascade Range for both general interest in the geology of the central High Cascades and specialized study of the many challenging geologic problems of the region.

Field Geology of the Northwest Quarter of the Broken Top 15' Quadrangle, Deschutes County, Oregon, by E.M. Taylor of the Department of Geology at Oregon State University, has been published as DOGAMI Special Paper 21. This section of the Broken Top quadrangle covers a portion of the area east of the Three Sisters and north of Broken Top, on the east side of the High Cascade crest in the Deschutes National Forest. The publication includes a 20-page text and a geologic map at the scale of 1:24,000.

This report is the second publication of the author's many years of intensive work in the area. The first results were published by DOGAMI in 1978 as Special Paper 2, *Field Geology of S.W. Broken Top Quadrangle, Oregon,* covering the adjacent area of Broken Top itself.

The text discusses the general geology of the study area in the context of the geologic history of the High Cascades. It then describes the mapped rock units, of which the volcanic units have been differentiated to such detail that the author had to go beyond the established system of geologic map symbols to identify them properly. Thus, for instance, 22 units of Pleistocene basaltic andesite were found in the study area—out of over 40 units identified by the author in his work so far. An appendix lists chemical analyses of over 100 rock samples from the study area.

The separate geologic map sheet shows, along with the rock units, the approximate boundaries of volcanic ash lobes, of Pleistocene glaciers, and of crests of recessional moraines. It also identifies number and location of each analyzed sample.

The new report, DOGAMI Special Paper 21, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $5. Orders under $50 require prepayment. □

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Paleontology in Oregon: Workers of the past

by Melvin S. Ashwill, Amateur Paleobotanist, 940 SW Dover Lane, Madras, Oregon 97741

During the past year, we have printed several short articles about the history of the Oregon Department of Geology and Mineral Industries. This paper delves deeper into the history of the study of geology in Oregon, as it presents biographical information about early-day paleontologists in the state. Oregon is rich in fossils, and the early-day scientists who were first on the scene had a rare opportunity to make exciting discoveries. Later paleontologists carved out their own special areas of interest, but all contributed to the still-unfolding story of Oregon's geologic history. Space does not permit a more detailed discussion of the scientists presented herein, but we hope that even this brief introduction will breathe life into names often cited in the literature. Publications by the individual paleontologists are not cited in this paper, but information about them appears in the *Bibliography of Oregon Paleontology: 1792-1983,* by Elizabeth L. Orr and William N. Orr, which was published by the Oregon Department of Geology and Mineral Industries in 1984. *—Editor*

INTRODUCTION

"As he came down from the quarry one day carrying his geologist's pick and hammer and a large specimen of rock, he found a stone mason at work preparing a large block from the quarry for building purposes. He stopped suddenly and holding up his own specimen said, 'Gaylor, what would you think if I should give this piece of rock a blow with my hammer and find a spray of leaves inside?' Gaylor stared with incredulity as Mr. Condon placed his piece of rock on a solid foundation, carefully studied its probable line of cleavage, struck a sharp blow, and the two sides fell apart, revealing a beautiful spray of leaves. He himself was delighted with the result, but when he looked up with a smile into the face of the stonecutter, he found him white with fear and astonishment, for to him, it was nothing short of a miracle. No explanation seemed to relieve the poor man's superstition, and he could never quite forgive the minister who he believed was in league with the spirits."

This incident in the life of Thomas Condon, as related by his daughter, Ellen Condon McCornack (McCornack, 1928), exemplifies the kind of excitement at the moment of discovery that has led paleontologists to spend countless hours, often wet, hot, or cold, in almost inaccessible places, doing their chosen work. The thrill of becoming—in the split second it takes to break open a rock—the first person ever to have viewed this image of life that had been imprisoned thousands or millions of years ago never pales for those who enjoy the study of ancient life.

Few realize it, but we in Oregon are surrounded by a veritable gold mine of fossil treasures that can be found in almost every corner of the state by those who trouble themselves to learn how. This is not true in all parts of the world. In many places, past conditions have worked against the preservation of life's evidence in layers of rock. Really old rocks, such as those deposited during the Precambrian, have few fossils, because life forms were much less common then. Also, most organisms during that time were soft bodied and therefore seldom preserved. In addition, many older rocks have been so altered, deformed, or changed in some way that any fossils that they may have contained have been destroyed or are not recognizable.

As Condon and others recognized early on, Oregon is a geologically young land. Our most ancient fossils are middle Devonian in age and are only about 370 million years old. Nevertheless, this state has a wealth of history locked in its rocks. Conditions were favorable for the preservation of fossil plant and animal remains during certain periods of Oregon's past, and uplift and erosion have fortuitously exposed these remains to us in many places—and in surprising ways. For instance, beachcombers along the central Oregon coast may not only pick up modern seashells but also pry Miocene shells from rocks at the same beaches. Furthermore, some of the fossils look so fresh that they are commonly mistaken for modern shells. Fossil hunters from all parts of the world travel to Oregon to share in our bonanza.

In this paper, we will look at some of the paleontologists who in the past literally "dug up" the facts. Wherever possible, we will include dates of birth and death of these scientists.

THE FIRST FOSSIL ENTHUSIASTS: NATIVE AMERICANS

Little is known about the first fossil hunters in Oregon. Fossils were sometimes used as ornaments and amulets by native Americans, as evidenced by the finding of occasional fossils, some pierced for stringing, preserved in old living sites and burials.

A few years ago, an archaeology research team from the Oregon Museum of Science and Industry's (OMSI) Hancock Field Station found an Indian fossil collection (Joseph Jones, personal communication, 1986). At the time, Brian Gannon, now a geologist-archaeologist in Alaska, was in charge of a dig on the Pentecost Ranch about 3 mi east of Camp Hancock, near Fossil, Oregon. At OMSI site WH357, the group excavated several house pits superimposed one over the other (est. age 11,000 years). In a corner of one of the pits, at a depth of 1 m, five rock slabs with fossil leaf impressions on them were found in a stack. The site is not far from a lower John Day Formation fossil leaf locality presently under study.

ESTABLISHING A FOUNDATION: 19TH CENTURY WORKERS

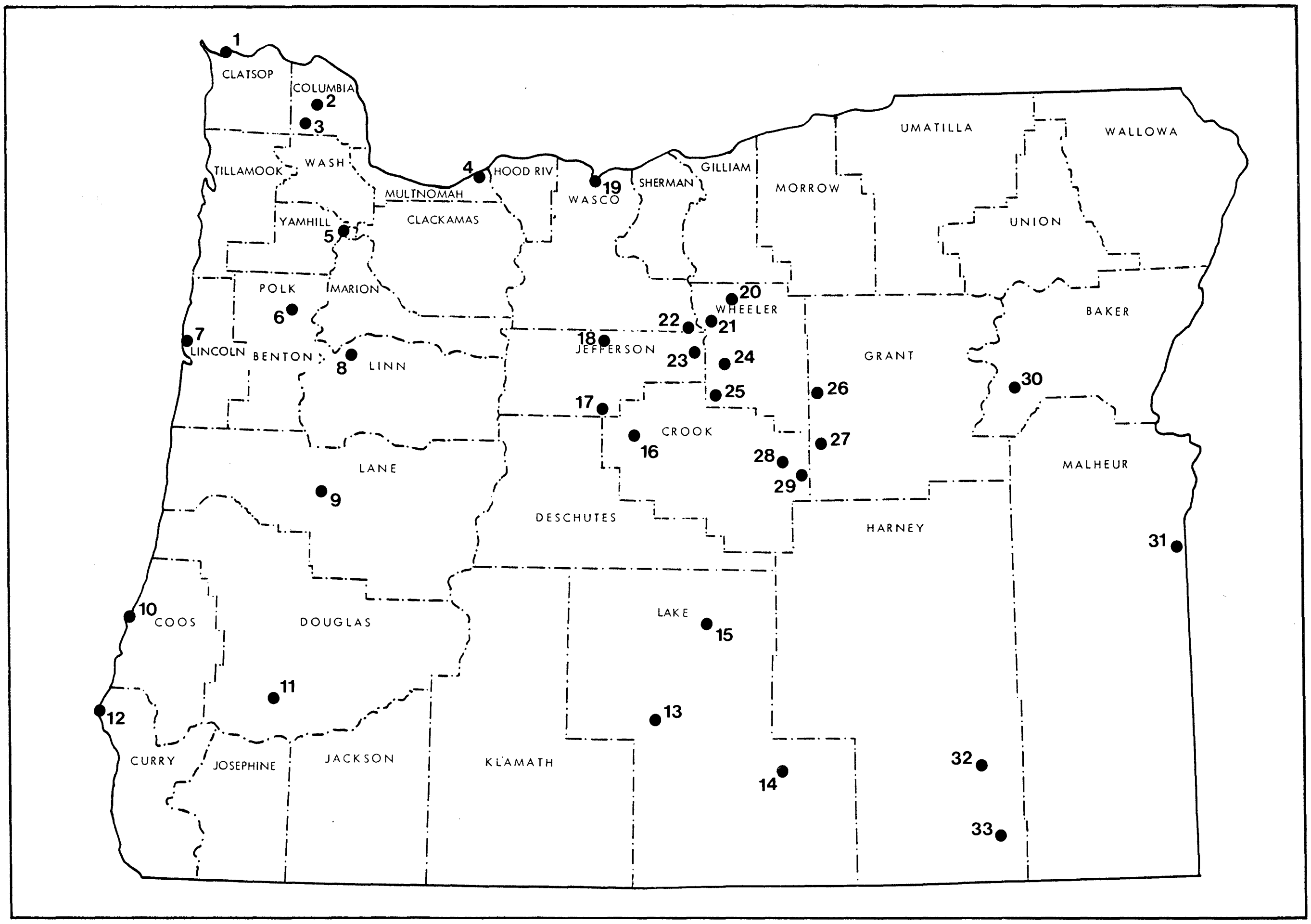
During the first half of the 19th century, Oregon was a frontier, with few permanent settlements. It was only in the 1840's that educational institutions above the elementary level were established. Fossils found by settlers or travelers were sometimes referred to eastern scientists for study.

Archibald Menzies, J.K. Townsend, H.C. Perkins, J. Hall, and J.W. Bailey

The first recorded reference to Oregon fossils seems to have been made by Archibald Menzies (see Orr and Orr, 1984), when he wrote in 1792 of invertebrate fossils that Captain Vancouver and his crew recovered from Cape Blanco. The sparse treatment of Oregon fossils in the first half of the 19th century also includes a discussion by J.K. Townsend of Astoria Formation mollusks, a description of fossil elephant bones found on the banks of the Willamette River by Ewing Young and studied by H.C. Perkins, and two papers by J. Hall (see Orr and Orr, 1984) on fossils found during Fremont's 1845 expedition. Beginning in 1845, J.W. Bailey produced a series of four papers on the diatoms of Oregon (see Orr and Orr, 1984). These reports all resulted from material brought back from reconnaissance expeditions of the United States government. By 1848, settlers were moving into the area, and this increase in population is reflected in the increase in the number of fossil studies that began to appear.

J.D.Dana (1813-1895)

Among the countless ships that have been wrecked on the Columbia Bar, the *Peacock* in 1841 carried part of Lt. Charles Wilkes' exploration expedition. On the ship was J.D. Dana, geologist and



Map showing Oregon's major fossil collection localities mentioned in this paper. Key to numbers:

1 *Astoria*
2 *Pittsburg Bluff*
3 *Keasey Formation*
4 *Moffet Creek*
5 *Newberg*
6 *Dallas*
7 *Lincoln County beaches*
8 *Scio*
9 *Goshen*
10 *Coos Bay-Cape Argo*
11 *Riddle*
12 *Cape Blanco*
13 *Summer Lake*
14 *Warner Valley*
15 *Fossil Lake*
16 *Prineville*
17 *Gray Butte*
18 *Gateway*
19 *The Dalles*
20 *Fossil*
21 *Hancock Canyon*
22 *Currant Creek*
23 *Cherry Creek*
24 *Bridge Creek*
25 *West Branch Bridge Creek*
26 *John Day Fossil Beds*
27 *Mascall-Rattlesnake Fossil Beds*
28 *Beaver Creek*
29 *Suplee*
30 *Unity Reservoir*
31 *Succor Creek*
32 *Alvord Creek*
33 *Trout Creek*

naturalist. Making his way ashore in a lifeboat, Dana made use of this unscheduled stop to collect Miocene mollusks from the Astoria Formation (see Orr and Orr, 1984).

T. Condon (1822-1907)

When the clipper ship *Trade Wind* rounded Cape Horn in 1852, it brought to the West one of the most remarkable men ever to work in Oregon paleontology. Thomas Condon, "the father of Oregon geology," and his bride Cornelia were missionaries. Rev. Condon's deep interest in the natural sciences was not unusual in an era when many other clergymen also pursued scientific avocations.

Born in Ireland, Condon grew up on Manhattan Island, New York. As a young teacher in central New York state, he collected trilobites and other marine fossils. When he and his family settled at The Dalles, then gateway to the gold fields at Canyon City, his duties with the church did not inhibit his scientific curiosity. Within a few years, he accumulated cabinets of fossils that were not only a topic of conversation for most of the populace but also of great interest to traveling officials and scientists from the East. "In talking with Captain McNulty or George Naggs, the affable purser, they would be advised to see Mr. Condon's geological collection. So about four o'clock of any pleasant day, the Condon home might be opened to a party of from two to twenty or more ladies and gentlemen who were eastern tourists" (McCornack, 1928).

It is a tribute to Condon's rare talents that he became a self-educated geologist and paleontologist through collecting, trading fossils for publications, and maintaining a stream of correspondence. In his later years, he was named Oregon's first state geologist (1872), and he finished his career as the University of Oregon's first professor of geology (1872-1905). He was well liked by students and faculty and universally regarded as an effective teacher and counselor. He was the pioneer stratigrapher of the state and was in communication with the leading geologists and paleontologists of the day (Addicott, 1981). Among the important scientists with whom Condon

Table 1. *Individuals discussed in this paper and their major fossil collection areas. Numbers are keyed to locality map.*

Anderson 11	Marsh 26,27
Bones 21	Menzies 12
Brogan 15,16,17,18,24,25	Merriam 26,27
Chaney 4,17,19,21,24,25,27	Packard 7,10,15,27,28
Condon 1,7,10,15,19,22,23,24, 26,27,28,29	Perkins 5
	Sanborn 8,9
Cope 15,28	Schenck 2,3,7,9,10
Dall 1,7,10	Sternberg 15
Dana 1	Stock 26,27,28
Diller 11	Townsend 1
Emlong 7,10	Weaver 2,3,7,10
Hancock 21,30	Whiteaker 15
Hannibal 10	Wortman 15

met or corresponded were O.C. Marsh, E.D. Cope, Joseph Leidy, S.F. Baird, Joseph Henry, Clarence King, H.S. Osborn, J.S. Newberry, F.V. Hayden, Joseph LeConte, C.H. Sternberg, W.B. Scott, J.C. Merriam, William Dall, and Jacob Wortman (one of Condon's students). Condon's primary contributions were in collecting and teaching. He wrote the first text on Oregon geology and published a few papers on fossils (see Orr and Orr, 1984). The "Dr." sometimes seen in his title probably resulted from his theological degree.

T.A. Conrad (1803-1877)

A brilliant, self-educated naturalist who never actually came to the Pacific Northwest, Timothy Conrad was the foremost authority on Tertiary paleontology in the United States during the mid-1800's (Addicott, 1981). Conrad (see Orr and Orr, 1984) described fossil mollusks from the Miocene Astoria Formation. He has been described as an enigmatic eccentric who was absentminded, moody, and often melancholy. He also has been accused of being too brief with his fossil descriptions (Moore, 1962, 1971). Conrad wrote to a friend in 1863, "I go Monday to help H. (James Hall, Director of the New York Geological Survey) ferret out my skulking species of Paleozoic shells. May the recording angel help me. God and I knew them once, and the Almighty may know them still. A man's memory is no part of his soul" (Merrill, 1924).

J.S. Newberry (1822-1892)

The explosive growth of railroads in the mid-1800's provided the side benefit of a great deal of geological information gained from the accompanying surveys and explorations. Many fossils were found in actual construction work, notably the famous "fossil fish cut" west of Rock Springs, Wyoming. John Strong Newberry, a Connecticut-born medical doctor with far-ranging scientific interests, accompanied Lt. R.S. Wilkenson's expedition on one such trip beginning in San Francisco and ending at The Dalles on the Columbia River. Although Newberry made some collections of minerals and fossils (chiefly floral) at this time, his main contribution to Oregon paleontology came later, when he supported Condon's efforts by describing his fossil plants in the literature (see Orr and Orr, 1984) and when he gave Condon some financial aid for his collecting trips.

O.C. Marsh (1831-1899) and E.D. Cope (1840-1897)

Paleontologists are frequently asked, "How much money are your fossils worth?" In truth, most fossils can be gotten merely by searching and therefore do not command high prices. Two 19th-century paleontologists were partly responsible for the popular fallacy that fossils are worth large amounts of money. O.C. Marsh of Yale University and E.D. Cope of the Philadelphia Academy of Sciences were brilliant and dedicated vertebrate paleontologists, each of whom had been endowed with large family fortunes. In their eager and highly competitive race to build complete collections, they hired professional collectors and also spent large sums of money to purchase good specimens, thus leaving a legacy of a paleontological spending spree.

Marsh collected with Condon in the Mascall beds in 1871 (McCornack, 1928), then visited The Dalles, where he examined Condon's large collection. He returned to The Dalles in 1873 to photograph and study some of the fossils. As the founder of the Peabody Museum, Marsh sent important scientific papers to Condon and bought and borrowed specimens from him. The well-publicized resentment that Condon developed when he was not able to get some of his loaned specimens returned until after Marsh's death may have been due to Marsh's avarice, as is commonly thought. It is equally possible that the specimens were held so long because of Marsh's chronic problem of having collected masses of material. He simply was never able to keep up in his studying of the fossils. In 1982, the writer was told by Bruce Tiffney, Yale paleobotanist, that to this day, occasional graduate students in need of thesis material will break open boxes of Marsh's unstudied specimens.

Starting in 1872, letters were exchanged between Cope and Condon (McCornack, 1928). Cope tried to get Condon to collect for him, but an arrangement had already been made with Marsh. Eventually Condon did send Cope packages of "duplicate" materials. Cope responded by paying for them, as well as supplying Condon with large quantities of up-to-date scientific literature. The latter was invaluable to Condon, remote as he was from any large literary collections. Two of Cope's paid collectors, C.H. Sternberg and J.L. Wortman, gathered fossils for him at Fossil Lake and the upper Crooked River. In 1879, Cope himself made a foray into Oregon. After collecting at Fossil Lake and Beaver Creek (upper Crooked River), he visited Condon (then at the University of Oregon) and examined the fossils in his collection. True to form, he immediately published his Oregon observations (see Orr and Orr, 1984).

One of Marsh's outstanding contributions was his elucidation of horse evolution in America. Some of the material crucial to this study came from Oregon (Marsh, 1874).

R.W. Shufeldt and John Whiteaker

The extensive early collections from the Fossil Lake Pleistocene, including those by O.C. Marsh, E.D. Cope, Governor John Whiteaker, C.H. Sternberg, Jacob Wortman, and Thomas Condon, have provided grist for numerous studies. Early settlers near Silver Lake, Oregon, reported that fossils were sometimes removed by the wagonload. Shufeldt alone published ten papers on fossil birds from Fossil Lake over a span of twenty years (see Orr and Orr, 1984).

W.H. Dall (1845-1927)

The first comprehensive study of the coastal Oregon invertebrates was published by Dall (see Orr and Orr, 1984). A prolific writer on mollusks during the late 19th and early 20th centuries, he worked from the Smithsonian Institution. Dall was a compulsive worker and was known to have kept fossil shells on hand at the dinner table, examining them between dinner courses (Addicott, 1981). Dall collected briefly in Oregon, but more importantly, he did valuable support work for others, including J.S. Diller.

J.S. Diller (1850-1924) and F.M. Anderson

For three decades at the turn of the century, J.S. Diller, geologist for the U.S. Geological Survey (USGS), conducted definitive studies on the stratigraphy of southwestern Oregon. He made extensive use of paleontology in his work (see Orr and Orr, 1984). Frank M. Anderson, an Ashland, Oregon, native, who for a short time was one of Diller's assistants, went on to publish several papers on the invertebrates (chiefly Cretaceous) of the same area (see Orr and Orr, 1984).

J.L. Wortman (1856-1926)

Surely, among the careers of Oregon paleontologists, that of Jacob L. Wortman must be the most curious. Born of pioneer stock and a native of the state, Wortman determined to make himself into a good paleontologist. He left the University of Oregon in 1887 and within 10 years had made a name for himself as a collector and paleontologist and had also added a medical degree to his qualifications. He had been by then anatomist for the U.S. Medical Museum and demonstrator of anatomy at Georgetown Medical College, Washington, D.C. There is some question about the degrees attached to his name in the literature. The University of Oregon archives do not list him among those having been granted a degree (Dorothy Gunness, written communication, 1985).

A brilliant collector, anatomical reconstructionist, and writer, Wortman was named assistant curator of vertebrate paleontology at the American Museum of Natural History under Henry Osborn. He was known as a warm and highly competent teacher, having produced definitive works in paleontology (see Orr and Orr, 1984) that remain classics. Paradoxically, at the peak of his success, he closed the book on his meteoric career following a series of frustrating administrative squabbles. He then married and settled in Brownsville, Texas, where he spent the remainder of his life as a pharmacist and drug store owner. He refused to practice or even read of his former profession.

Wortman had studied under Condon at the University of Oregon and held him in high regard, saying to him, "If my efforts are in the end to be crowned with success, I will always feel that no one will be entitled to a larger measure of credit for the same than yourself....To your charming and attractive method of presenting the subject, I owe probably more than anything else the impressions which afterward led me to take it up for a life work" (McCornack, 1928).

J.C. Merriam

The Oregon that J.C. Merriam encountered on his first paleontological expedition into central and eastern Oregon definitely had a frontier flavor. In his journal of the expedition, scientist Loye Miller wrote the following on Sunday, May 28, 1899: "In the afternoon at 2:00, we passed through the little town of Antelope. Sunday was a busy day, stores doing a good business, pack horses in the streets, and saloons going full blast. The little 'burgh' has the reputation of being the toughest town in the country. As we came up the grade on this side, a drunken horseman swayed along to where we were, muttered some inarticulate babble, finally toppling off his horse by the road. We tied his horse to the fence and left him to sleep it off" (Miller, 1899). Even today, fossil hunters like to view their expeditions into central Oregon in an adventurous light. It is obvious that Miller's imagination was gripped by the frontier aspect of the freight stop on the way to Oregon's gold fields.

By the turn of the century, Merriam was well into a distinguished career as a teacher and researcher in paleontology at the University of California (UC) at Berkeley. A product of Berkeley himself, Merriam spent many years there and was responsible for the training of numerous individuals who conducted important paleontological investigations in Oregon during the first half of the 20th century. He headed many fossil collecting trips in central and eastern Oregon and published results from them over a period from 1899 to 1927 (see Orr and Orr, 1984).

FLESHING OUT THE RECORD: 20TH CENTURY WORKERS

By the beginning of the 20th century, Oregon was losing some of its pioneer flavor. With several good-sized cities, rail, sea, and highway transportation, and good mail and telegraph service, the people of the state now looked upon themselves as more a part of the mainstream of civilization. The sketchy paleontological work of the 1800's had laid a good foundation of knowledge that was now rapidly built upon by a series of capable people.

W.M. Fontaine and H. Hannibal (1889-1965)

Definitive studies of the Jurassic floras near Riddle and Port Orford were furnished by Fontaine, while Hannibal published some useful papers on invertebrates in Oregon (see Orr and Orr, 1984).

E.L. Packard

Earl Packard can be regarded as Condon's successor. He was the first paleontologist since Condon to spend a long tenure in Oregon colleges. Trained by J.C. Merriam at Berkeley, he began his Oregon career at the University of Oregon 10 years after Condon. During the depression years, when it was decided that the University of Oregon would focus on the humanities while Oregon State Agricultural College (now Oregon State University) would deal with the sciences, Packard and other science teachers moved to the Corvallis campus. Packard was very active in field work in Oregon and helped train many of today's outstanding paleontologists. His 28 references cited in the *Bibliography of Oregon Paleontology* (Orr and Orr, 1984) reflect his impact on the profession.

R.W. Chaney (1890-1971)

The person with the greatest number of references cited under his name in the Oregon paleontology bibliography (Orr and Orr, 1984) was not an Oregonian at all. Born in Illinois, Ralph Works Chaney studied at the University of Chicago. He spent 49 years of his life at Berkeley, where he did paleobotanical research and teaching. He traveled to several continents in amassing his collections and, at the close of his career, was recognized as a monumental figure internationally. Today, almost two decades after publication of his last paper, this author found Chaney's name in 11 of the first 14 recent paleobotanical publications to be picked up. He published until three years before his death at the age of 81 and prior to his death was compiling material for a paper on the Eocene West Branch flora from near Mitchell, Oregon.

Chaney's first brush with paleobotany was in 1916, when he collected plant fossils in the Columbia Gorge. This discovery encouraged him to return countless times to collect in Oregon. His last visit was in 1969, when he, along with some of his former students, made sentimental stops at some of his past collecting areas, including the Gray's Ranch (now Alaska-Pacific Ranch) locality on the Crooked River.

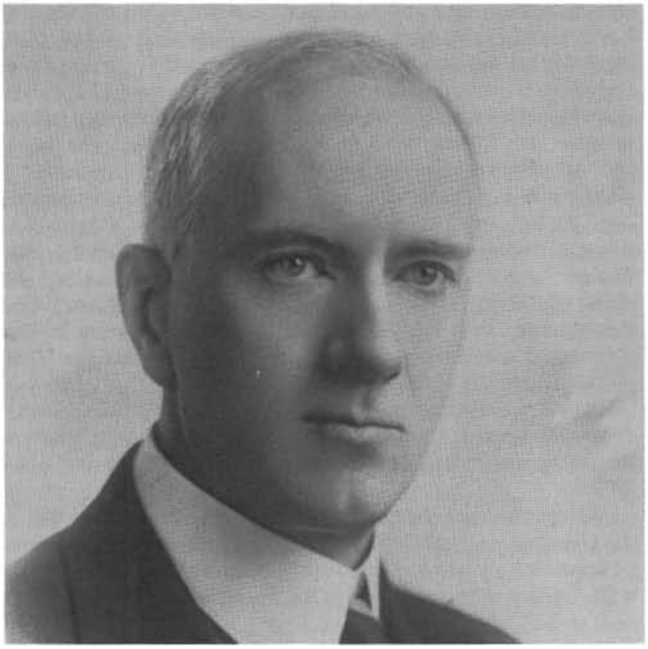
Roy Chapman Andrews took Chaney with him on his famous 1925 trip to the Gobi Desert of Mongolia. This was the first of several trips to the Orient for Chaney, the most memorable being his trip to central China to collect and verify the existence of a "living fossil," the Dawn Redwood *(Metasequoia)*.

Chaney is remembered with affection by his former students. C.J. Smiley, paleobotanist at the University of Idaho, reminisced:

"I think I may have learned more from him on field trips than at any other time. He was a funny man. By that, I mean humorous. He had a good sense of humor, and he had his quirks of personality that helped make him interesting. One was that he was a very close man with a dollar. He hated to spend money unnecessarily. On field trips, for instance, he tried in every way to economize. One of his favorite foods was bananas, and he liked them very ripe—almost squishy. Once he stopped in a small-town grocery store for provisions and found some overripe bananas. On learning the price, he talked to the owner at length about the fact that the price should have been discounted due to the condition of the fruit. When the shopkeeper was unmoved, Chaney pointed out the very short shelf life for the bananas and the likelihood that if not sold now they would spoil on the shelf. Still not gaining a better price, he stormed out of the store without his favorite food.

"Another time, he paid the going price for some fresh cherries at a store but became petulant and outraged when, just a short way down the road, he came upon an entire orchard of ripe cherries going to waste. Receiving permission from the owner, he spent an hour of effort in picking an enormous quantity of fruit. For some time after that, he was quite smug and happy about the money he had saved by not buying these additional cherries at the store."

Chaney's observations on Tertiary floral paleoecology had a tremendous impact on the direction of thought on this topic (Gray



Charles E. Weaver. Photo courtesy Warren O. Addicott, USGS.

Phil F. Brogan. Photo courtesy John Philip Brogan.

and Axelrod, 1971). His extensive collections from Oregon played a critical role in the formulation of this paleoecological synthesis. Chaney's letters, numbering well over 1,000, are housed in the rare-books section of the University of Oregon library.

J.P. Buwalda, E.W. Berry, G.D. Hanna, and E.L. Furlong

Also contributing to Oregon paleontology during the first half of the 20th century were J.P. Buwalda, who conducted studies of vertebrate fossils; E.W. Berry, who published studies of plant fossils; G.D. Hanna, who described Oregon invertebrate fossils; and E.L. Furlong, who was a vertebrate paleontologist.

C. Stock

One of J.C. Merriam's early students at U.C. Berkeley was Chester Stock. In company with Merriam, Furlong, and Chaney, as well as independently, he spent many seasons collecting and describing vertebrate fossils from the John Day and Mascall Formations (see Orr and Orr, 1984).

The pronunciation of the name "Mascall," incidentally has been a source of confusion over the past decade. Some put the accent on the first syllable, while others place it on the last. The formation was named for the owner of a ranch just southeast of Picture Gorge in the basin holding the formation. The writer talked with David Mascall of Prineville, Oregon, who is a descendant of that early rancher. Mascall states that although the name, which is of French derivation, may be accented on the final syllable in France, the traditional pronunciation in his family has always been "MASS-kl," with the accent on the first syllable.

H.G. Schenck (1897-1960)

A pioneer in micropaleontology, Hubert G. Schenck studied under Packard at the University of Oregon. His publications, both on individual localities and regional stratigraphy, were important contributions (see Orr and Orr, 1984). He taught at Stanford University and was an exceptionally impressive teacher, probably the best in his field (Addicott, written communication, 1986).

E.I. Sanborn

Ethel Sanborn, who was a former student of Chaney and at one time was a paleontologist at Oregon State Agricultural College, published significant papers on the Goshen, Comstock, and Scio floras (see Orr and Orr, 1984). These provided important data for interpretation of past climatic conditions. The study of ancient climates is enjoying a surge of interest now, and her references are essential for those workers currently involved in paleoclimatological investigations in our region.

R.W. Brown, C.A. Arnold, and G.F. Beck

Also working in Oregon during the middle of this century was R.W. Brown, then of the USGS. In addition to fossil plants, he described Oregon's only known fossil bat (see Orr and Orr, 1984). Chester A. Arnold of Michigan University, a specialist in primitive vascular plants, found tree fern fossils in Oregon (see Orr and Orr, 1984). G.F. Beck of Central Washington State University collected extensively and described fossil woody tissues from Oregon (see Orr and Orr, 1984).

C.F. Weaver (1880-1958)

When any study of natural history focuses on a given area, the scope of the study inevitably, like ripples in water, widens to include nearby areas. So it was that, when one of the giants of Pacific Northwest invertebrate paleontology, Charles F. Weaver, set out to study western Washington's fossils, he ended up contributing to Oregon paleontology as well. For all of his life a strong hiker, Weaver, like many other thorough field paleontologists and geologists of his day, spurned the automobile. He worked on foot and used public transportation only when forced to do so. He was one geologist who could never be accused of taking all his samples and making all his observations from roadside localities. Weaver's field work in the Pacific Northwest was mainly completed prior to 1920. It created a solid base upon which later workers have built.

P.F. Brogan (1896-1983)

If you had been born, as Philip F. Brogan was, around the turn of the century in remote central Oregon and had spent your youth hearing the bagpipes of Scottish shepherds echoing in the wild hills, having your name included in an article on Oregon paleontology would have seemed rather remarkable. Brogan, however, was a remarkable man. He holds a special place among Oregon's contributors to historical geology. His articles in the *Geological Socie-*

ty of the Oregon Country Newsletter (see Orr and Orr, 1984) and for decades in the Sunday edition of the *Oregonian* did much to popularize geologic and paleontological knowledge in the state. Despite an incredibly demanding work schedule as associate editor of a daily newspaper, Brogan found time to collect many Tertiary fossils. The horse, rhinoceros, and plant fossil specimens he located were often turned over to professionals or museums, and access to his collection was freely given. He tramped the hills with most of the early workers in central Oregon, including R.W. Chaney, Earl Packard, and the geologist Howel Williams. His help was sought by so many that it seemed for decades as though the first duty of anyone starting work in the area was to be introduced to Brogan. The literature is rife with acknowledgments of his help. Brogan guided R.W. Chaney to the Deschutes fossil flora locality as well as the West Branch fossil flora locality, each of which furnished critical paleobotanical data. Brogan's personal papers in the archives of the University of Oregon are a mine of historical information.

A.W. Hancock (1884-1960)

Alonzo W. "Lon" Hancock, for whom Camp Hancock and Hancock Canyon are named, was another serious amateur paleontologist who has contributed much to Oregon paleontology. As an employee of the U.S. Postal Service in Portland, he and his wife spent their spare time collecting fossils. In the 1940's, he, along with his friend Tom Bones, began to concentrate on the "nut beds" area, which includes the famous deposit of fossil seeds, nuts, and leaves adjacent to what is now Hancock Canyon. This spot is a few miles east of the old Clarno ferry (now a bridge) over the John Day River.

Hancock amassed a large fossil collection, including vertebrates and plants, which now forms the core of paleontological collections and exhibits of the Oregon Museum of Science and Industry (OMSI) in Portland, Oregon. Viola Oberson (written communication, 1986), who knew the Hancocks well and was also instrumental in the start of OMSI, says that Mrs. Hancock, following the death of her husband, insisted that a display room be provided before she would release the collection.

Hancock played a significant role in introducing paleontology to young people over a period of several decades. At first taking small groups of students camping with him, he later formalized an educational program in conjunction with OMSI. After more than 30 years of growth, OMSI's Hancock Field Station, headed presently by Director Joseph Jones, currently conducts a variety of programs for all ages, including classes and camps for school-age children and adults, four college classes, and the University of Oregon field camp, that cover a wide range of subjects including earth science, astronomy, life science, and cultural history.

Camp Hancock alumni

The "distinguished alumni" list of Camp Hancock is impressive. Among those who participated in camp studies before becoming professionals are Steven Manchester, now a paleobotanist with Indiana University; Herbert Meyer, paleobotanist associated with the paleontological museum at UC Berkeley; Jack Wolfe, paleobotanist with the USGS in Denver and a world authority on paleoclimates; Dave Taylor, paleontologist at Portland State University; Thomas McKee, presently of Portland, Oregon; Bruce Welton, former curator at the Los Angeles County Museum of Natural History, now with Standard Oil Co.; Eric Gustafson, formerly with the Museum of Natural History at the University of Oregon and the University of Nebraska; Analisa Berta, San Diego State University; John Faulhaber, Burns area; and John Armentrout, former director of Camp Hancock and now with Mobil Oil Co.

T.J. Bones

With a name like "Bones," might not one be predestined for paleontology? Hancock's friend, Thomas J. Bones of Vancouver, Washington, was one of a kind. In the early 1940's, Hancock interested Bones in the seeds and nuts fossilized by the thousands at Camp Hancock. With amazing patience, Bones acquired the skills needed to recover the tiniest of seeds from the stony matrix and over the years amassed a huge collection. Bones shared his findings widely, and references to his work appear in many studies by other paleontologists. His lifelong occupation was in the printing trade, working with photographs and engravings. He used his expertise in photography and developed unique methods that produced breathtaking color enlargements of his fossils. Major portions of his collection are now preserved in the Smithsonian Institution's National Museum of Natural History and at the Department of Geology, Indiana University. Smaller but very impressive collections are on display at the John Day Fossil Beds National Monument Visitors Center and at Whitman College in Walla Walla, Washington.

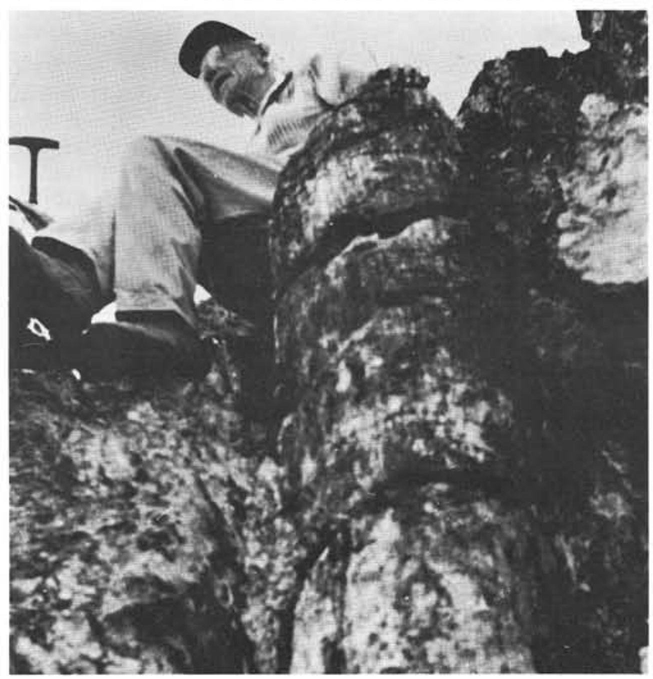
Bones told this author that the rhinoceros tooth figured by Stirton (1944) and attributed to Hancock was actually seen and collected by his wife Lorene, who subsequently gave it to Hancock. This was the first vertebrate fossil to be found in the Clarno Formation (Bones, 1979).

This author was flabbergasted when Tom Bones stated that of the countless hours he had spent collecting fossils over an interval of more than 40 years, almost all of them had been spent within a 50-ft radius. The question is "Can this record ever be matched?"

D.R. Emlong (1942-1980)

From the time that Douglas Ralph Emlong recovered his first fossil (a sea-lion vertebra) at Fogarty Creek as an eighth grade student until his tragic death in 1980 at the age of 39, he built an unparalleled assemblage of marine mammal fossils. He collected intensively for decades, most of the time unfunded, and persevered in the face of daunting adversities.

Emlong's work astounded the professional world of his speciality. Clayton E. Ray of the Smithsonian Institution, who was his major mentor, is lavish in his praise of Emlong for his impact on the field of marine mammalian paleontology. He states: "Emlong's work certainly deserves all the recognition it can get. A full biography would be warranted" (Ray, written communication, 1986). Pertinent published observations by Ray include the following: "The incom-



Lon Hancock, sitting atop the large, upright petrified tree trunk in Hancock Canyon near Fossil, Oregon. Photo courtesy University of Oregon Archives, Phil Brogan Collection.

parable 'Emlong Collection' remains a dynamic testimonial to his uncanny ability and intense dedication" (Ray, 1980). Also: "It may be confidently anticipated that the Emlong Collection will contribute substantially toward greatly improved understanding of the origin, evolution, and systematics of several major lineages of marine mammals" (Ray, 1976).

During his earlier collecting years, Doug Emlong prepared large exhibits based on his finds for agate shows, for which he won blue ribbons. As the size of his collection grew, he opened his own museum at Lincoln Beach. Emlong's collection eventually came to the attention of the Smithsonian Institution, and in 1968 he sold most of his material to that organization. The shipment of the fossils weighed 40,000 pounds and required the use of two moving vans for the cross-country trek to Washington, D.C. (Ray, 1976). The remainder of his collection contains numerous invertebrate fossils (some beautifully agatized), including examples of the chambered nautilus and similar creatures (Jennie V. Emlong, written communication, 1986). These remain at his mother's home in Tenino, Washington.

Over the last several years, more than two dozen scientists have been working with Emlong's fossils (Ray, 1980). It is estimated that it may be decades before they have all been thoroughly exhumed from their matrix and described. Emlong himself described one of his prized finds, an archaic whale, in a University of Oregon Museum of Natural History Bulletin (Emlong, 1966).

Emlong's extraordinary ability to find fossils that others might easily have overlooked is legendary. When the Smithsonian Institution brought him to Washington, D.C., he even spotted a vertebrate fossil in a Potomac River bank when crossing a bridge while entering the city. Additionally, in prospecting the Empire Formation type locality at Coos Bay (Ray, 1976), where professional paleontologists saw nothing worth collecting, Emlong recovered the skull and part of the skeleton of a gigantic seal along with other fossils. The fact that he then found himself forced to trade his heavy hammer for enough gasoline to get him home underscores his unusual dedication to his work.

Guy Pierson, who has been collecting in Emlong's home area with great success, says of Emlong's work, "His work rewrote the paleontology of marine mammals" (Pierson, personal communication, 1986). Pierson also has the feeling that everywhere he goes and in everything he does, he is walking in Emlong's footsteps.

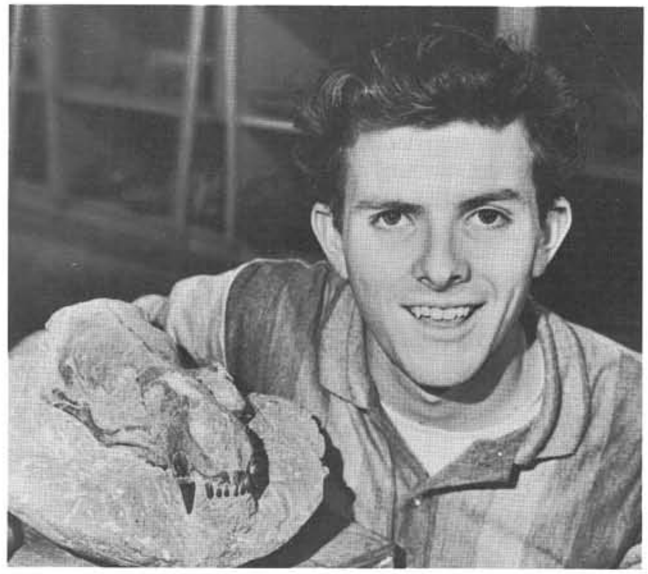
"Douglas specialized in collecting marine mammal fossils, most of which were chipped from bed rock with pick-axe, chisel, and rock hammer when the tide receded. The process often required continued work, with the tide coming in waist deep, to pry and roll out the chunks of rock before they were again covered with sand—possibly for years" (Jennie V. Emlong, written communication, 1986). Certainly Doug Emlong epitomized the dedicated collector, who is willing to persist for interminable hours in harsh weather and unfavorable terrain in anticipation of the exciting discovery.

SUMMARY

The rich stores of fossils in Oregon's rocks have piqued the curiosity of its people since well before the time of Lewis and Clark. Formal study of these fossils began with the earliest of explorations to the area.

Nineteenth-century paleontological work resulted in the discovery of now-classical coastal invertebrate localities (Dana), fossil mammal localities in the John Day Formation (Condon, Cope, and Merriam), and the Pleistocene vertebrate faunas from Fossil Lake (Shufeldt, in particular) for birds.

Major accomplishments in the 20th century include the following: (a) taxonomic description and paleoecological interpretation of Tertiary floras (Chaney); (b) descriptions of Miocene-Pliocene vertebrate faunules and pioneering quantitative mammalian paleocommunity analysis (Shotwell); (c) collection of Clarno nuts and seeds (Bones); (d) discovery of the Clarno mammal site (Hancock); and (e) fossil marine mammal collection (Emlong).



Douglas Emlong, holding the head of an ancient porpoise fossil that he collected from the Astoria Formation near Newport. Photo courtesy Oregonian.

ACKNOWLEDGMENTS

Steven Manchester, David Taylor, Warren Addicott, and William Orr reviewed the manuscript of this paper and contributed valuable information. Others who reviewed portions, added information, and furnished photographs are John Philip Brogan, Jennie V. Emlong, Viola L. Oberson, C.J. Smiley, Jane Gray, C.E. Ray, Joseph Jones, and Ellen J. Moore. Dorothy Gunness of McMinnville, Oregon, who furnished much of the information on Jacob Wortman, is a family historian with a wealth of information.

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Madin joins DOGAMI staff

Ian P. Madin has joined the staff of the Oregon Department of Geology and Mineral Industries (DOGAMI) as a geologist. A recent graduate of Oregon State University, Madin's research interests include structure, neotectonics, and collisional plate boundaries. His past work includes structural and neotectonic studies in the Pakistani Himalayas and adjacent to the Alpine Fault in New Zealand.

Ian P. Madin

Madin was engaged to coordinate neotectonic and seismic hazard research for northwestern Oregon funded by the National Earthquake Hazard Reduction Program of the U.S. Geological Survey. □

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